# JOURNAL OF THE A·I·E·E·

NOVEMBER 1927

PUBLISHED MONTHLY BY THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 WEST 39TH ST· NEW YORK CITY

# MEETINGS

of the

## American Institute of Electrical Engineers

(See Announcements This Issue)

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REGIONAL MEETING, Great Lakes District No. 5
Chicago, November 28-30, 1927

WINTER CONVENTION, New York, N. Y.
February 14-17, 1928

ST. LOUIS REGIONAL MEETING, District No. 7
March 1928

BALTIMORE REGIONAL MEETING, District No. 2
April 1928

NEW HAVEN MEETING, District No. 1
May 1928

SUMMER CONVENTION, Denver, Colo.
June 25-29, 1928

## MEETINGS OF OTHER SOCIETIES

Society of Naval Architects and Marine Engineers, New York, N. Y., November 10-11, 1927.

The American Society of Mechanical Engineers, Annual Meeting, New York, N. Y., December 5-8, 1927.

American Physical Society, Chicago, November 25-26; Nashville, December 28-30, 1927.

American Society of Civil Engineers, Annual Meeting, New York, N. Y., January 18-20, 1928.

American Institute of Mining and Metallurgical Engineers, Annual Meeting, New York, N. Y., February 20-23, 1928.

# JOURNAL

OF THE

# American Institute of Electrical Engineers

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A REQUEST FOR CHANGE OF ADDRESS must be received at Institute headquarters at least ten days before the date of issue with which it is to take effect. Duplicate copies cannot be sent without charge to replace those issues undelivered through failure to send such advance notice. With your new address be sure to mention the old one, indicating also any changes in business connections.



(The Journal of the A. I. E. E. is indexed in Industrial Arts Index.)

# Current Electrical Articles Published by Other Societies

**Engineers & Engineering,**

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Oil-Electric Locomotives Win Favor with Chicago & Northwestern Railway, by C. H. Vivian

September 1927

Underground Transmission at 66,000 Volts in Philadelphia, by H. S. Phelps

**Iron & Steel Engineer,** September 1927

Electrification of the Tata Iron Works at Jamshedpur, by S. Ghosh

Inductive Time Limit Control, by N. L. Mortensen

Power Factor Correction, Effective Power and Reactive Power, by W. H. Feldman

**Minn. Fed. Arch. & Engineering Society Bulletin,** September 1927

Electricity and Improved Railway Efficiency, by R. Budd

**Institute of Radio Engineers, Proceedings,** October 1927

Long Wave Radio Measurements at the Bureau of Standards in 1926 With Some Comparison of Solar Activity and Radio Phenomena, by L. W. Austin

Radio Atmospheric Disturbances and Solar Activity, by L. W. Austin

Two Contrasting Examples Wherein Radio Reception Was Affected by a Meteorogical Condition, by E. H. Kincaid

A Radio Inter-Communicating Service for Railroad Train Service, by Henry C. Forbes

**Western Society of Engineers Journal,** August 1927

Hydroelectric Turbines in General and for Niagara in Particular, by F. Nagler

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*Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences*

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## Suggested Change in Institute Publications

The continued increase in the amount of material published by the Institute in the JOURNAL and the TRANSACTIONS has been made evident to the membership by the constantly growing size of these publications, and there is little doubt that in the future this rate of growth will increase. Each succeeding year witnesses an increasing demand for publishing more and more material, and the advent of numerous regional meetings, a most desirable activity which is being fostered by the Institute, has already decidedly influenced this demand for the publication of more papers.

The publications of the Institute comprise one of its most important activities, and it is the policy of the Institute to encourage this activity to the utmost possible extent, but it has recently become apparent that the volume of our publications is rapidly outgrowing the methods of publishing which are in vogue at present. As an example of this, Volume 45 of the TRANSACTIONS, covering the year 1926, which has just been distributed, contains about 1300 pages and weighs nearly ten pounds, which is practically the limit for this style of binding. Any farther increase in the number of pages would tend to break down the binding by its own weight, yet Volume 46, if the same system is followed will contain 1500 pages, which is considered beyond the limits of practicability.

A simple solution of this problem would apparently be to divide the volume into two parts of 750 pages each, but this involves a prohibitive expense. These books are now furnished to subscribing members at a price of two dollars a volume while the cost of production is now four dollars a volume, and any farther increase in manufacturing cost must be avoided. It is therefore apparent that the Institute is faced with the alternative of rejecting at least 200 pages of papers from the next volume of TRANSACTIONS, or of modifying its present methods of publication so as to take care of the increase in production without materially increasing its expenses.

The Publication Committee has recognized for some time that this situation was rapidly approaching and it has devoted considerable time to the study of a feasible and appropriate solution of the problem. As the result of its investigations, after considering the matter from numerous angles and view points, a modification of our present methods has been recommended by this committee to the Board of Directors. The proposed plans are given here rather fully in order to ascertain the reaction of the membership to them before their final adoption, and under these plans there is no doubt that our expected increases in published matter can be taken care of for several years with little if any increase above our present costs.

The principal modifications suggested by the Publication Committee are as follows:

(1) Publish the TRANSACTIONS quarterly in pamphlet form, charge a nominal price as at present, and secure entry in Post Office as second-class mail.

(2) Publish the JOURNAL as at present except to limit the length of any one article to 4 or 5 pages.

(3) Publish pamphlet copies of all papers in full as at present for distribution previous to meetings and send them free on request when published in the JOURNAL in abridged form.

(4) Make rule that all manuscripts of over 4000 words accepted for publication must be accompanied by an abridgment or JOURNAL story not to exceed about 4000 words in length.

The reasons for these recommendations may not be readily apparent to those not familiar with the details of publishing, and therefore some explanation of the results to be accomplished is in order.

Under (1), the binding and mailing costs of the TRANSACTIONS will be greatly reduced. The binding of four quarterlies in pamphlet form will mean a saving of 30 cents per volume. Under second-class mail a uniform rate of 1½ cents per pound will obtain, making the mailing cost of four quarterlies about 15 cents, as against the present parcels post rates which average about 40 to 50 cents per copy and run as high as $1.22 to California.

It is necessary to adopt pamphlet binding in order to receive second-class mailing entry. Some members will doubtless desire cloth-bound quarterlies to match the previous issues of the TRANSACTIONS, in which case arrangements can be made to supply cloth-bound copies for an additional sum covering the actual extra cost of binding and mailing.

An incidental advantage of this plan is that members would receive the quarterlies every three months and would not have to wait over a year and a half as at present to obtain papers and discussions in permanent form for reference.

Under (2), it is believed that the practise of abridging all papers that are over four or five pages in length

will make the JOURNAL a much more readable paper for practically all the Institute membership. Very few if any readers of the JOURNAL are equally interested in all the papers published. Most members of the Institute are specialists in one or two branches of electrical engineering and are only casually interested in other branches. Each member will desire the complete papers on such subjects as specially interest him and these he will obtain free on application. The papers in the JOURNAL will consist of concise abridgments giving the essential features and conclusions of the complete papers, and this is as much as the general reader wants to know about papers outside his special field. It is sufficient to keep him well posted in all fields of electrical engineering without bothering him with details in which he is not interested.

Recommendations (3) and (4) need no farther comment as they are obviously necessary features of the plan outlined. It may be objected by some that the contemplated length of abridgments is too small but this question has been carefully considered by the Publication Committee and the conclusion reached that no papers have been published by the Institute that could not be satisfactorily summarized in four or less JOURNAL pages.

This plan has been devised with a view to meeting the criticism frequently made, that the double publication of all our material, first in the JOURNAL and again in the TRANSACTIONS, constitutes a very inefficient use of our resources. Only one other engineering society of which we know duplicates its entire publication in an annual volume, and that volume is pamphlet bound. Other societies issue annual volumes but very little of their contents has previously been printed in monthly publications. In no other society has double publication been carried to the extent to which it has been carried by the A. I. E. E.; and by avoiding this duplication, enough money will be conserved to go far towards publishing the increasing number of papers desired.

It is highly desirable that this plan, or such modification of it as may be judged advisable, be adopted at an early date as the preparation of Volume 46 of the TRANSACTIONS is being held in abeyance pending a decision on this subject, and the only alternative appears to be the omission of at least 200 pages of the material which has been accepted for this volume. The Publication Committee will welcome any suggestions from the membership leading to practical improvements in its plans; but such suggestions should be made very promptly so that the current work on the TRANSACTIONS shall be delayed as little as possible.

These recommendations are published by the order of the Board of Directors so that comments from the membership may be received up to December first. Suggestions received prior to this date will receive full consideration of the Board in its final disposition of the matter in December.

## Members Invited to Visit Sections

Members of the Institute are reminded that they are always welcome to attend meetings of any Section of the Institute located in any city which they may be visiting. Furthermore, the officers of Sections are always glad to meet such visiting members, and, when convenient, to receive notices of such visits in advance. This is particularly true of visiting members from a distant part of the country, who may be able to give a brief talk upon some topic of interest. For example, informal talks upon any recent engineering developments in one part of the country, are invariably of interest to Institute Section members in another territory.

Sections located in the western part of the United States and Canada have frequently indicated their desire to know in advance of contemplated visits from eastern members, and to have brief addresses from such members. If any member, planning a trip to a distant part of the country, will notify Institute headquarters in New York, the National Secretary will be glad to forward the information to the officers of the Sections in the territory to be visited, and otherwise assist in arranging visits which will prove to be profitable and interesting both to the visitor and the membership of the Sections concerned.

In connection with a trip to attend the Pacific Coast Convention at Del Monte, I visited during August and September of this year, the Sections in Saskatchewan, Vancouver, Seattle, Portland, San Francisco, Los Angeles, Salt Lake City and Denver. Some of these gatherings were in the nature of Section meetings; others, luncheon or dinner meetings of executive and other committees; and still others were in the nature of joint meetings with other organizations of engineers. In every instance, evidence was found of continued and increasing interest in the Institute's activities and of the usefulness of the Institute to the individual members in numerous ways. I was impressed with the interest of the members in the work of the Institute and the value of the Section and District form of organization.

I heartily appreciated the many courtesies extended to me by the officers of all of the Districts and Sections visited, and take this opportunity of urging upon members that they make similar visits whenever the opportunity affords.

BANCROFT GHERARDI
President, A. I. E. E.

## Early Inventor Honored

A tablet was recently erected at Williamstown, Vt., to the memory of Thomas Davenport, blacksmith and pioneer inventor of the electric motor. In 1834 he was granted a patent, No. 132, for an electric motor which, it is claimed, if it were in force today, would cover every electric motor now in use.

# An Instrument for Measuring Short-Circuit Torque

BY G. W. PENNEY[1]
Associate, A. I. E. E.

***Synopsis.***—*The torque produced by a short circuit or other transient will produce a corresponding acceleration of the rotor. If the rotor is not connected to a load the acceleration of the rotor will be directly proportional to the torque. A small instrument is described which can be attached to the end of the shaft of the machine to be tested. This instrument records the instantaneous acceleration of the rotor, the corresponding torque being calculated. The acceleration is measured by two separate methods. The first method gives points on an acceleration—time curve and the second gives a continuous record of the torque. The acceleration is recorded on the oscillogram so that by using a six element oscillograph a simultaneous record can be obtained showing both the acceleration and the short-circuit currents. The mechanism for closing the short circuit at the desired point of the voltage wave and the method of checking the accuracy of the instrument are also described. A record from an actual short-circuit test is shown. The results of the tests will be discussed in a later paper. The instrument can also be used for measuring sudden shocks on motors and other rotating machinery.*

## Introduction

In order to design machines to withstand all possible operating conditions and yet not waste material, it is necessary to know the magnitude of the greatest forces which may act on the machine under the worst possible conditions. At the instant of a short-circuit surge, or when synchronized out of phase, enormous forces may act on a machine. The end windings are inherently rather weak mechanically and usually these are the first parts to be injured by a short circuit. These failures are caused by local magnetic forces, but in a few instances, the resultant torque of the machine has caused failure. One of the first large vertical shaft generators of low reactance sheared off the foundation bolts and turned through a considerable angle. In another case, a 6000-kv-a. frequency changer set had the frame supporting foot broken off and the holding down bolts stretched when the set was connected to the line out of phase.

These failures show the enormous forces produced by short circuits and other transients. In order to make machines sufficiently strong to withstand these abuses to which they are frequently subjected and yet not waste material, the maximum torque which may be developed under abnormal conditions must be known. Because of its transient nature, this torque is very difficult to calculate or measure. Methods thus far developed for calculating short-circuit torque are rather questionable because the assumptions which must be made do not accurately represent the actual conditions.

So far as the writer is aware, the only previous attempts to actually measure this torque have been by recording the oscillations of the rotor, using the torsiograph or similar instrument giving a space—time curve of the movement of the rotor or by measuring the voltage generated by a small generator connected to the shaft of the machine short circuited[2]. The determination of torque from a space—time record is very uncertain because the torque is proportional to the second derivative, *i.e.*, curvature of the space—time record. As is discussed later, this is very unsatisfactory for this purpose. The measurement of the voltage generated by a small direct-connected generator is much better but this method requires taking the slope of the record which is not entirely satisfactory. This paper outlines an analysis of the general problem of measuring torque produced by short circuits and other transient phenomena and describes the instrument which was developed. The instrument was designed to be attached to the end of the shaft of a machine and gives a record on the oscillogram of the instantaneous acceleration of the rotor which is proportional to the instantaneous torque provided the machine is not connected to an external load. If it is desired to measure the torque developed when the machine is short circuited while running under load, the test must be arranged so that the torque developed by the machine short circuited can be determined from the acceleration of its rotor and the known characteristics of the connected load or driving motor. The instrument was designed for the one purpose of measuring the acceleration of the rotor produced by a sudden pulsating torque. It was intended to give an accurate record of the first torque cycle and a fairly accurate record of succeeding torque cycles. It was designed for torque frequencies not exceeding 120 cycles and accelerations of 500 radians per sec. and above. It can be readjusted for measuring lower accelerations provided the frequency is reduced. In addition to studying short circuits, it may be useful

1. Power Engineering Dept., Westinghouse Elec. & Mfg. Co.

*Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Pittsfield, Mass., May 25-28, 1927.*

2. The torque developed by a short circuit was measured by H. Rikli, (*Bulletin Association Swisse des Electriciens* No. 5, 1925). He measured the voltage generated by the exciter which was operated on open circuit with its field supplied by storage batteries. The torque was of course proportional to the rate of change of voltage. If the torque developed had a sinusoidal form, it would be fairly easy to determine the rate of change of voltage, but with the irregular torque developed by a short circuit, it is very difficult to measure the peak acceleration.

for studying shocks on rolling mill equipment and similar applications.

## Selection of Type of Instrument

There are many methods which might be used to measure the torque produced by a short circuit. Perhaps the most obvious method would be to mount the stator on trunions and attempt to measure the torque. This would require large, clumsy, and expensive apparatus, and since the torque is of a pulsating nature, it would be extremely difficult, if not impossible, to measure this torque accurately, for any known method of measuring such a large pulsating force would allow some motion of the stator and any such motion absorbs force in the inertia reaction of the stator, so that the torque measured would not be the same as the actual torque developed.

Another method of attack is to measure the effect on the rotor. If the rotor is sufficiently rigid so that it can be regarded as a single mass, the acceleration of the rotor will be directly proportional to the torque applied (assuming that the rotor is not connected to any other device). This general scheme was adopted since it requires only a record of the acceleration of the rotor and therefore lends itself to a small instrument which may be readily attached to any machine.

The pulsating nature of the torque produced by a short circuit is the major difficulty in measuring the torque accurately. For instance, if an attempt were made to measure the actual force acting on either the stator or the rotor a very slight movement would absorb a large force in the inertia reaction, resulting in a large error in the recorded force. For example, the stator of a representative 20,000-kv-a., 60-cycle generator has a moment of inertia of $\dfrac{2,600,000}{g}$. Then if this stator were mounted on trunions and perfectly free to move and if a sinusoidal torque of 60-cycle frequency and having a peak value equal to the normal torque of the machine were acting on the stator, the amplitude of the resulting movement would be only 0.00002 radians. At an 80-in. radius, the total movement (double amplitude) would be only 0.0032 in. This movement of 0.0032 in. assumes a sinusoidal torque whose average value is zero so that it has no tendency to produce continuous rotation and with the stator mounted on trunions, the only effect is to produce this torsional oscillation of 0.00004 radians total movement which absorbs the full pulsating torque in the inertia reaction of the stator. This is merely given as an example of the enormous force required to produce a very small oscillation of a stator or rotor at 60-cycle frequency. If an attempt were made to measure the torque developed during short circuit by measuring the force exerted by a stator mounted on trunions, it is evident from the above discussion that the allowable movement of the stator is very small. The problem is further complicated by the probability of resonance[3]. The same general difficulty applies to other methods of measurement, to that in any method of measurement, the flexibility of the instrument must be carefully considered for any slight relative movement permitted may result in very large errors. It is much easier to control the natural frequency in a small instrument which measures the acceleration of the rotor than in a large device for measuring force, so that the small instrument should be more accurate and reliable as well as cheaper and more convenient.

There are several possible methods of measuring the acceleration of the rotor. One method would be to obtain a space—time curve showing the instantaneous position of the rotor as a function of time. The second derivative of this record (*i. e.*, the curvature) would then give the acceleration. But in this method any vibration of the recording mechanism would indicate a torque which did not exist. In general, the tendency is to exaggerate errors when a record must be differentiated. A record of instantaneous speed could be obtained, but this would have to be differentiated to get the acceleration so that excessive accuracy would be required in the speed—time record in order to obtain a reasonably accurate record of acceleration. Thus, to secure an accurate record as well as to save time in interpreting the record, the instrument should measure acceleration directly.

The acceleration could be measured electrically by generating a voltage proportional to the rotor speed and impressing this voltage across a condenser. The charging current would then be proportional to the acceleration of the rotor. This method is possible, but to secure sufficient current to give a reasonable deflection on the oscillograph, the apparatus must be rather large or amplification must be used. There is considerable chance for error due to e. m. fs. induced by stray fields at the time of short circuit and by the variation in drop across the brushes which must be used to collect the current. The most serious disadvantage is that it does not lend itself to a small instrument and the calibration is neither as convenient nor as accurate as in the device adopted.

The general scheme of measuring the force required to drive a small flywheel is believed to be the most accurate method available for measuring the acceleration of the rotor. It is very convenient since it can be incorporated in a small instrument which can be attached directly to the shaft of a machine, and since it can be calibrated statically by applying a known torque to the flywheel, the corresponding acceleration being calculated from the moment of inertia of the flywheel.

3. The torque transmitted to the foundation by a stator mounted with some flexibility is discussed by Mr. Soderberg in an article published in the April, 1924 issue of the *Electric Journal* (p. 160). This article covers the steady state conditions. For a transient such as a short circuit, the solution is much more complicated.

### The Instrument

The instrument decided on combines two separate devices for measuring the acceleration of the rotor. The first merely gives eight points on the acceleration-time curve and the second gives a continuous record of the acceleration. These devices are in a single, very rigid casting which can be attached to the end of the shaft of the machine to be tested. The acceleration is recorded on the oscillogram giving a simultaneous record of acceleration and of short-circuit current. Figs. 1 and 2 show two views of the instrument attached to a small 1200-rev. per min. alternator.

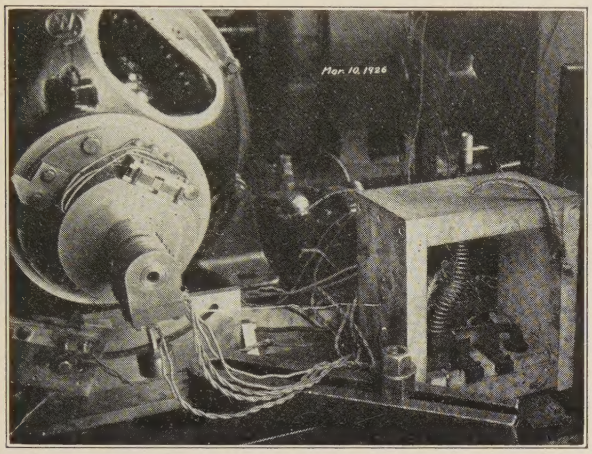


Fig. 1—Illustration of the Instrument Attached to the Shaft of a 100-Kv-a. Generator

The device which records points on the acceleration—time curve consists of several small disk flywheels mounted on and free to rotate on the instrument shaft. Fig. 3 is a cross-section of the instrument showing one of the disk flywheels and also shows the wiring diagram for a group of flywheels. Each disk flywheel (*a*) has a projection (*b*) on its periphery which engages with a stop (*c*) on the body of the instrument. This stop also serves as an electrical contact. The flywheel projection is held against this stop by a spring (*d*) as shown in Fig. 3. The projection on the flywheel is made of hard rubber with a brass insert for a contact, so that current is carried through the spring, brass insert, and stop, being entirely insulated from the flywheel disk.

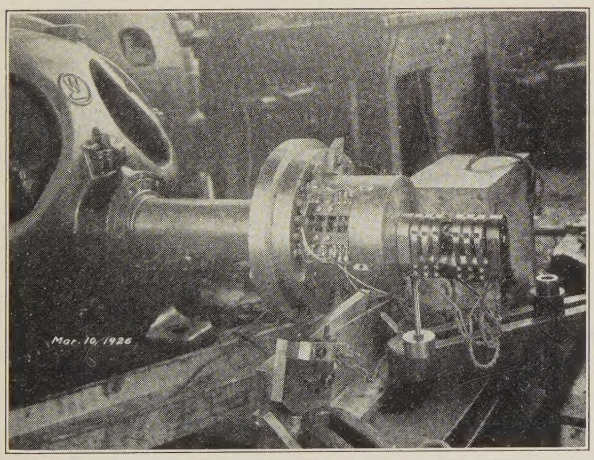


Fig. 2—Illustration of the Instrument

When the instrument is accelerated in a clockwise direction, the inertia reaction of the flywheel will tend to open the contact, but the spring will hold the contact closed until the acceleration force exceeds the spring force. As soon as this point is reached, the contacts will start to separate thus breaking the circuit and recording the time at which the acceleration reaches a value corresponding to the spring setting. By using several flywheels with different spring settings an acceleration—time curve can be plotted.

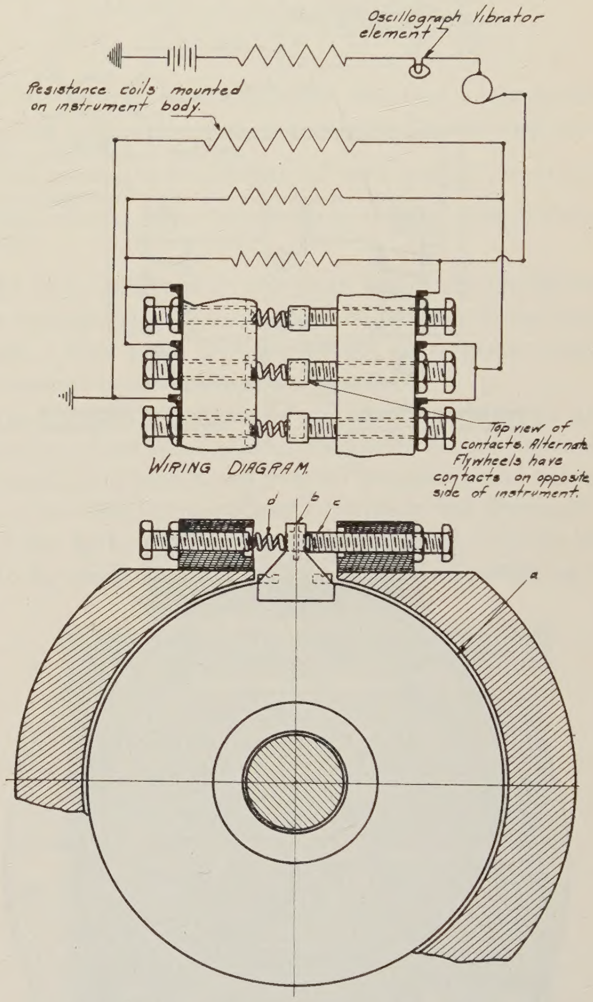


Fig. 3—Cross-Section Showing Disk Flywheel and Contact

This shows a disk flywheel and its contact. The time at which the contact opens shows when the acceleration reaches a certain value. The instrument includes eight of these flywheels. The wiring diagram shows the connection for recording the action of several contacts with one oscillograph vibrator element.

It is evident that at the instant when the contact pressure becomes zero, the contacts will start to separate very slowly at first and then more rapidly. If an appreciable separation of the contacts is required to break the circuit, a considerable time lag will be introduced. Fig. 5 shows the calculated rate of separation of contacts. It is evident that if a record of the instant

when the pressure becomes zero, can be obtained, the instrument is accurate, but if a separation of one 1/1000 of an inch is required, a considerable error is introduced. A resistance is connected across the contact so that opening the contact will merely produce a slight decrease in current and by using a small current

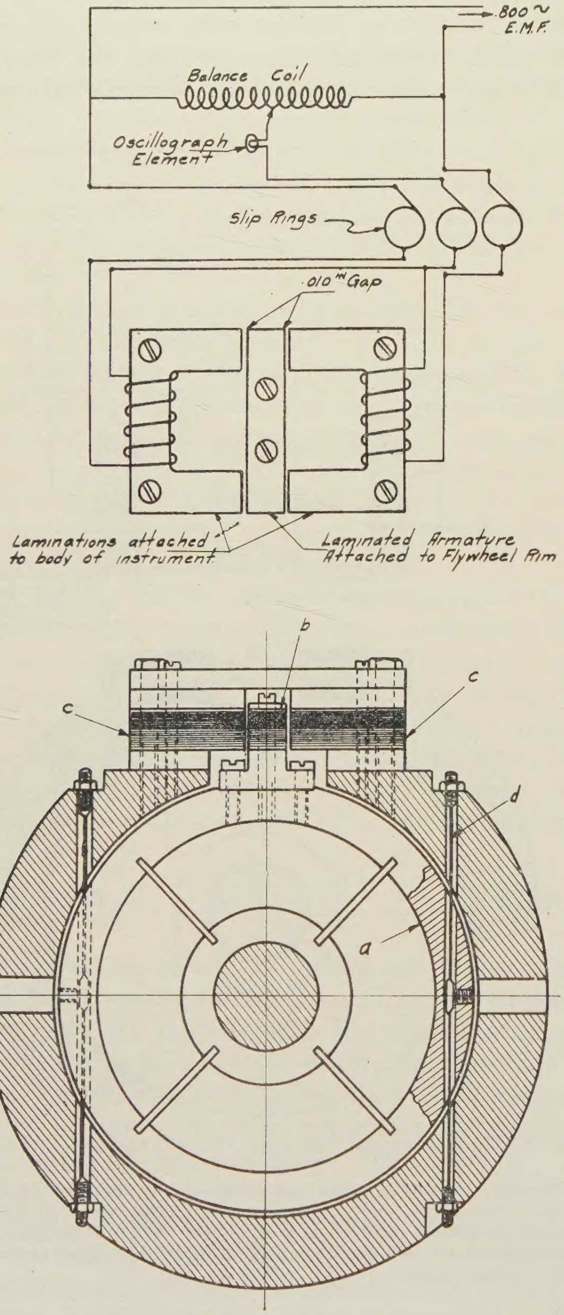


Fig. 4—Cross-Section Showing Magnetic Accelerometer

The instrument combines two independent devices for measuring acceleration. This is a cross-section showing the device which gives a continuous record of the acceleration. The wiring diagram is shown above.

and low voltage, and making the circuit as nearly non-inductive as possible, the contact separation required is reduced to a minimum. As described later, a calibration test was made which showed that in this circuit a change in the current can be observed almost at the instant when the contact pressure becomes zero.

Eight of these flywheels are mounted on the instrument shaft. Each flywheel is 5¼ in. in diameter and ⅜ in. thick at the hub, so that the axial space required is only three inch. The flywheels are connected in groups as shown in the wiring diagram (Fig. 3). In this way, several contacts are connected in series, each contact being shunted by a resistance. When any contact opens, there will be a certain decrease in the current. The values of resistance are chosen such that if the contacts open in the normal order, the steps in the current record will be approximately equal, but if they open in any other order, the steps will be unequal and the contact which opens can be determined from the value of resistance shunting the contact. In this way, a group of flywheels requires only one slip-ring and one oscillograph vibrator element.

In this device there is considerable time lag in the closing of the contacts and severe chattering after they

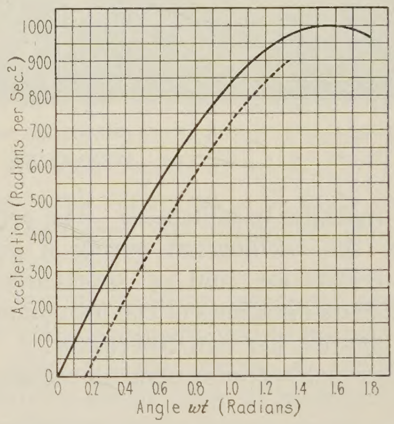


Fig. 5—Calculated Opening of Contacts

Full line shows the assumed sine-wave acceleration.

The dotted line shows the acceleration that would be recorded if a contact separation of 0.0001 in. were required to give a perceptible change in current. Actual tests showed a negligible time lag indicating that for the circuit used, the contact separation required to give a perceptible change in current was very much less than 0.0001 in.

close so that the record is of no value after the first torque cycle, but in a short circuit the main point of interest is the first torque cycle, so that for this purpose this instrument is very satisfactory.

The device which gives a continuous record of the torque consists of a flywheel rim mounted from a rigid hub with spokes which are flexible in a tangential direction. Then when the instrument is given an angular acceleration, the inertia reaction of the flywheel rim will deflect the spokes producing a relative tangential movement between the flywheel rim and body of the instrument. A magnetic device measures this relative movement which is proportional to the acceleration. Fig. 4 is a cross-section of the instrument showing this device for giving a continuous record of the acceleration. The flywheel rim ($a$) carries a laminated armature ($b$). Two sets of U-shaped laminations ($c$) are attached to the body of the instrument. Any relative tangential movement between the flywheel rim and

body of the instrument will increase one air-gap and decrease the other. Each set of U-shaped laminations carries a coil. The two coils are connected in a bridge circuit with a balance coil and oscillograph vibrator element as shown in the wiring diagram (Fig. 4). An 800-cycle e. m. f. is impressed across the coils. The balance coil can be adjusted to give approximately zero current for the neutral position of the armature.

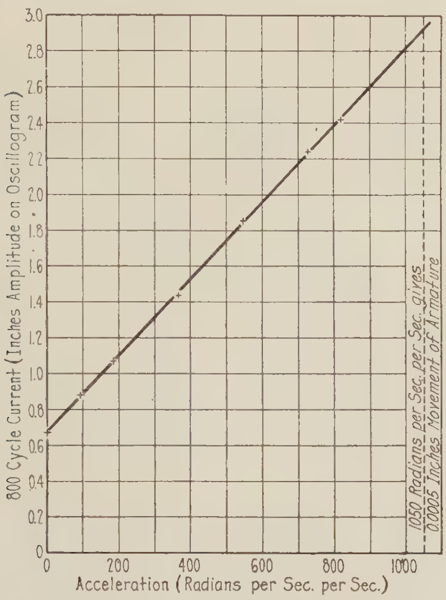


FIG. 6—CALIBRATION OF MAGNETIC ACCELEROMETER

Then any movement of the armature will decrease the inductance of one coil and increase that of the other, causing a current to flow in the oscillograph element. With negligible resistance, saturation, and leakage flux,

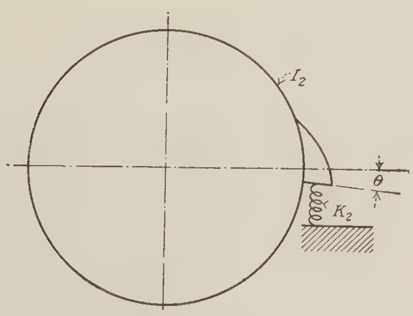


FIG. 7—SCHEME FOR CALIBRATION TEST

The instrument rotates at a known velocity and a projection on the flange strikes the spring "$K_2$" at $\theta = O$.

the oscillograph current will be proportional to the movement of the armature. For the oscillograms shown in Fig. 9, the only attempt to balance the resistance was by constructing the resistances approximately equal. To reduce the initial current further, the resistance and reactance should be balanced separately.

In an ideal instrument, the motion of the flywheel rim should be exactly the same as the motion of the body of the instrument so that the acceleration of the flywheel rim will be the acceleration which it is desired to measure. This would require the measurement of force without permitting relative movement. Practi-

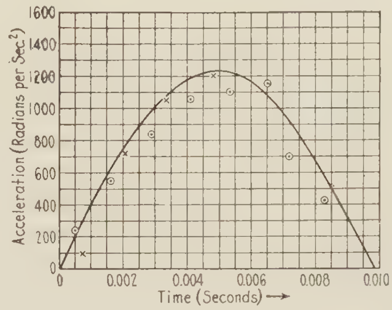


FIG. 8—RESULTS OF CALIBRATION TEST OF ACCELEROMETER

The full line shows the acceleration calculated from the initial speed and spring characteristics.

Points indicated by dot and circle (⊙) shows the acceleration as recorded by the magnetic device.

Points indicated by "x" are the points recorded by the disk flywheel contacts

cally, it is sufficient to have the motion of the flywheel rim substantially the same as the motion of the instrument. The error corresponding to a given relative movement is discussed in Appendix I.

In Appendix I, it is shown that to obtain a given accuracy a certain natural frequency of the flywheel is required, and for a given natural frequency and acceleration, the relative movement between the flywheel rim and the body of the instrument is fixed. If the error is to be small, the relative movement allowable is very

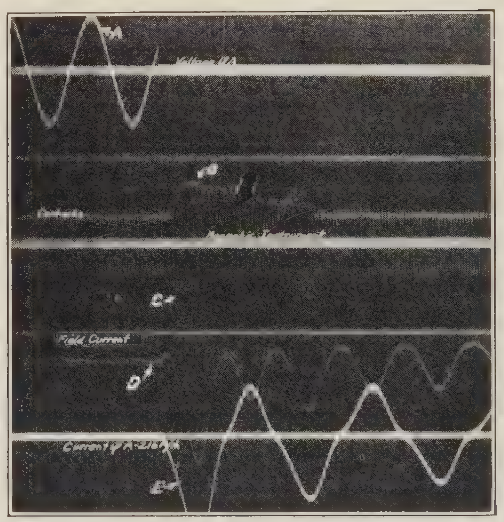


FIG. 9—OSCILLOGRAM SHOWING CURRENTS AND TORQUE FOR A SINGLE-PHASE SHORT CIRCUIT

A—Terminal voltage
B—Current through a group of contacts
C—800-Cycle current—the magnetic record of acceleration.
D—Field current
E—Current in short-circuited phase

small. In this instrument, the natural frequency of the flywheel is 400 cycles per sec. so that for an acceleration of 1000 rad./sec.[2] which is a fairly high value of acceleration, the corresponding relative movement between

flywheel rim and instrument body is only one-half mil.

Since this one-half mil of relative movement is between two parts rotating at high velocity and subject to severe vibrations at the instant of short circuit, very careful design is required to insure an accurate measurement. The instrument as constructed gives a 2-in. amplitude on the oscillogram for an armature motion of ½ mil, or a magnification of 4000 times. This gives a very satisfactory method of measuring the acceleration of the rim since the relative movement is so small that the motion of the flywheel rim is practically the same as the motion of the shaft.

This ½ mil of allowable movement does not mean that the absolute position of the flywheel rim must be located with any such accuracy. It does require however, that there be no relative movement permitted between the flywheel rim and body of the instrument except the elastic tangential movement of the flywheel rim which is proportional to the acceleration. To accomplish this, the flywheel rim is carried on flexible spokes so that the flywheel and body of the instrument behave as one piece of metal having the proper flexibility to permit a slight relative tangential movement, but with sufficient rigidity in other directions so that all other relative movements are negligible. The magnetic instrument must then measure minute relative tangential movement with accuracy. To accomplish this, the air-gaps are set as nearly alike as possible and the final balance obtained with the balance coil adjustment. Then a very slight movement of the armature can give a very large oscillograph deflection.

A slight torsional vibration of the flywheel rim will sometimes occur, but with the high natural frequency of the flywheel (400 cycles) this can readily be distinguished from other effects. Serious trouble might occur if there was a tooth pulsation or other disturbance having a frequency the same as the natural frequency of the flywheel. For this reason, it is desirable to be able to change the natural frequency of the instrument. It is also desirable to have a means of changing the sensitivity of the instrument. Both of these objects are accomplished by the auxiliary springs (*d* in Fig. 4), which give additional stiffness to the flywheel system. Each spring is merely a piece of piano wire stretched between two parts of the instrument body and with its midpoint attached to the flywheel rim. It is so arranged that the size of wire can be readily changed. For the small movement required, this gives the stiffness required in a very light spring.

The amplitude of the current recorded by the oscillograph is a measure of the movement of the armature from its neutral position. If this current is adjusted to be zero in the neutral position, a movement in either direction will produce an increase in the amplitude of the recorded current, but since the direction of the first acceleration of a short circuit is known, this is satisfactory. With negligible resistance, saturation, and leakage flux, the amplitude of the current recorded should be proportional to the movement of the armature. The instrument used can be set to give a slight initial deflection and a straight line characteristic in one direction, but not quite a straight line characteristic in the reverse direction. In this case, the main point of interest is the first torque peak, so that this adjustment was used. Fig. 6, shows a calibration curve for the instrument. The magnification can be increased by increasing the voltage applied to the instrument.

## Method of Calibrating the Instruments

The moment of inertia of each flywheel can easily be determined so that the torque corresponding to a given acceleration can be calculated. To calibrate the disk flywheel springs, a torque is applied to the flywheel rim using a spring balance. The torque is gradually increased until the contact opens as shown by watching the deflection in the oscillograph. Each spring can then be adjusted to give the desired value of torque required to open the contact.

In practise, the springs are adjusted roughly to cover the desired range and the torque required to open each contact measured and recorded as the calibration for that contact.

To calibrate the instrument which gives a continuous record, a known torque is applied by hanging scale weights from the flywheel rim and measuring the corresponding deflection in the oscillograph. By doing this for several values of torque, an acceleration—deflection curve can be plotted. This calibration curve is shown in Fig. 6. The method of calibration is very simple, so that if desired it can be checked before and after a test to be sure that nothing is out of adjustment.

By calibrating the instrument in this way, the oscillograph and acceleration measuring instrument are calibrated as a unit so that all errors are eliminated except those due to the difference between rotating and stationary conditions. Two of these errors which must be considered are the variation in contact drop at the slip-rings and any e. m. f. which might be induced by stray fields at the instant of short circuit. The effect of a slight change in contact drop is negligible since the reactance of the circuit is large compared to the resistance, so that a change in resistance will result in a change in phase angle, but only a very slight change in impedance.

Any currents induced by stray fields will have a low frequency compared to the 800-cycle e. m. f. supplied to the instrument, so that an induced current will merely shift the zero line and not affect the ampl tude of the 800-cycle record so that an induced current will not give an appreciable error. There is usually considerable lateral vibration at the instant of short circuit, but this does not produce angular acceleration in an accurately balanced flywheel.

As a check on the operation of the instrument in actually recording pulsating acceleration, a calibration

test was made in which a sine-wave acceleration of known frequency and magnitude was imparted to the instrument by rotating the instrument and allowing a spring to engage with a projection on the periphery of the instrument. This method is discussed in Appendix II. Fig. 8 shows the agreement between the calculated acceleration and the acceleration as measured by the instrument. The agreement between the records was considered very close for measurements of this kind.

## Closing the Short Circuit

The torque developed by a short circuit varies with the point of the voltage wave at which the short circuit occurs. In order to measure the maximum possible torque, it is necessary to close the circuit at the proper point of the voltage wave. To accomplish this, a switch is arranged to be tripped at a given position of the rotor. The switch is designed to close quickly (1/100 of a sec.) so that a small percentage of variation in the time required for the switch to close will give only a very small error in the time at which the switch closes. The position of the rotor at which the switch is tripped is adjustable. In making a test, one short circuit must be made with a known setting of the tripping mechanism. The point at which the switch is closed is noted on the oscillogram and the tripping device set ahead or back the required number of degrees to close the switch at the desired point of the voltage wave.

The switch shown in Fig. 1 was improvised using an ordinary knife switch. It is closed by very heavy springs and has a rubber bumper to absorb the shock at closing. The tripping device consists of a projection on the flange of the shaft coupling which engages with a very light phosphor bronze dog. This phosphor bronze dog can be moved in an arc of a circle to engage at the desired position of the rotor. This arc is graduated in degrees to facilitate setting the dog. This device can be seen at the bottom of Figs. 1 and 2. The dog is made as light as possible and is connected to the catch of the switch by a piece of small piano wire. These parts are very light, for if heavy, they would cause a serious jar of the instrument at the instant of short circuit which might destroy the accuracy of the record. A certain amount of flexibility is also essential to prevent breaking the parts due to the high speed at which they engage.

This device can be depended upon to close the circuit with less than 10 deg. variation from the desired position of the voltage wave, which is less than one-half thousandth of a second error. Prior to closing the short circuit, a piece of small fuse wire holds the phosphor bronze dog sidewise in a position where it will not engage with the rotating projection. A hand operated switch is used to start the oscillograph. This switch also connects 110-volts, d-c. power, directly across this small fuse wire, blowing the fuse and releasing the dog. Then as soon as the rotor reaches the proper position, the main switch will be tripped closing the circuit at the desired point of the voltage wave. In this way, closing the circuit and taking the record are controlled automatically so that all the operator has to do to take a record is to close a small instrument switch.

## Conclusion

Some tests have been made and these have shown remarkable agreement between the two separate methods of recording the torque. This fact, together with the calibration test, shows quite conclusively that the instrument is very accurate. Fig. 9 shows an oscillogram taken of a short circuit, the circuit being closed slightly off zero voltage. The armature current and acceleration of the rotor are recorded simultaneously. Fig. 10 shows the torque developed by a single-phase short circuit. A discussion of the results of the tests will be given in a later paper.

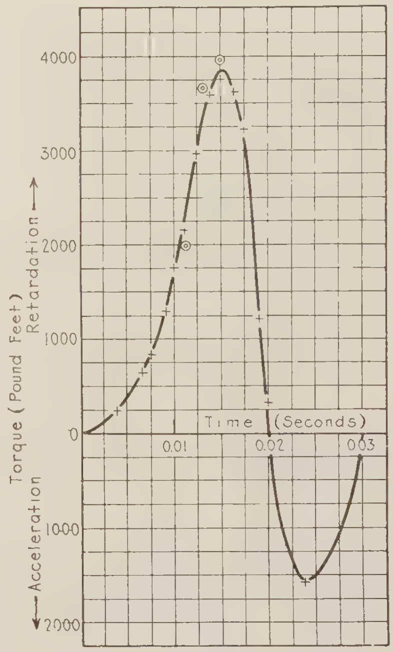


Fig. 10—Torque—Time-Curve for a Single-Phase Short Circuit

Points shown by dot and circle (⊙) show acceleration as recorded by opening of contacts

Points indicated by cross "+" show acceleration recorded by magnetic instrument (peaks of 800-cycle current)

The means of measurement used are old devices, merely redesigned and combined for the particular purpose desired. The idea of measuring linear acceleration by a mass held against a contact by a spring has been used frequently, and its adaptation to angular acceleration was suggested by Mr. Soderberg several years ago.

The idea of measuring small movements by the variation in inductance resulting from the change in air-gap has been used in many instruments and experiments. The magnetic device used for measuring the movement of the flywheel rim in this instrument was copied from an instrument built four years ago by Mr. J. G. Ritter, for measuring railway track stresses.

The author is indebted to many men in the Westing-

house organization for valuable suggestions and ideas used in designing the instrument and wishes to take this opportunity to thank them, particularly Mr. C. R. Soderberg, Mr. J. G. Ritter, Mr. J. W. Legg, and Mr. C. J. Fechheimer.

## Appendix I

In measuring the acceleration of a rotor by measuring the force required to drive a small flywheel, the flywheel should have exactly the same motion as the shaft, but since any known device for recording the instantaneous force allows a slight relative movement of the parts, the error due to this relative movement between flywheel and shaft must be considered.

Let

$\alpha_F$ = Acceleration of flywheel in rad./sec.$^2$

$\alpha_R$ = Acceleration of rotor of machine in rad./sec.$^2$

$\delta$ = Relative angular movement between rotor and flywheel.

$K$ = Spring constant of device driving flywheel (pound-inches per radian).

$I$ = Moment of inertia of flywheel

$\alpha_R = \alpha_F$ + relative acceleration between rotor and flywheel.

$$\alpha_R = \alpha_F + \frac{d^2\,\delta}{d\,t^2} \qquad (1)$$

But

$$K\,\delta = I\,\alpha_F \qquad (2)$$

or

$$\delta = \frac{I}{K}\,\alpha_F$$

Then assume that

$$\alpha_R = A \sin \omega\, t$$

Then

$$\alpha_F + \frac{I}{K}\,\frac{d^2\,\alpha_F}{d\,t^2} = A \sin \omega\, t$$

or

$$\frac{d^2\,\alpha_F}{d\,t^2} + \omega_c^2\,\alpha_F = \omega_c^2\,A \sin \omega\, t$$

where

$$\omega_c = \sqrt{\frac{K}{I}}$$

This gives

$$\alpha_F = C_1 \cos \omega_c\, t + C_2 \sin \omega_c\, t + \frac{1}{1-\left(\dfrac{\omega}{\omega_c}\right)^2} A \sin \omega\, t \qquad (4)$$

In this solution $\left[A\,\dfrac{1}{1-\left(\dfrac{\omega}{\omega_c}\right)^2}\sin \omega\, t\right]$ represents the steady state condition and $C_1 \cos \omega_c\, t + C_2 \sin \omega_c\, t$ represents the transient condition which will be damped out by friction. Thus in the steady state condition, $\alpha_F$, which is the acceleration measured, is equal to the actual acceleration of the rotor ($\alpha_R$) multiplied by the factor $\left[\dfrac{1}{1-\left(\dfrac{\omega}{\omega_c}\right)^2}\right]$. So that $\left[\dfrac{1}{1-\left(\dfrac{\omega}{\omega_c}\right)^2}\right]$ represents a fundamental error in this method of measurement. The smaller the value of $\dfrac{\omega}{\omega_c}$ can be made, the smaller will be the error. If $\dfrac{\omega}{\omega_c} = 1/4$, the measured value will be 6½ per cent high.

Any mechanical device for continuously recording force can be regarded as having a certain flexibility and as measuring the deflection due to the action of a force on this flexibility. Then if the value of $\omega_c$ is fixed by the allowable error, and if a given acceleration must be measured, the corresponding relative movement between rotor and instrument flywheel is fixed.

For, from equation (2)

$$K\,\delta = I\,\alpha_F$$

or

$$\frac{K}{I} = \frac{\alpha_F}{\delta}$$

or

$$\omega_c = \sqrt{\frac{\alpha_F}{\delta}} \qquad (4)$$

or

$$\delta = \frac{\alpha_F}{\omega_c^2} \qquad (5)$$

In designing this instrument, a natural frequency of 400 was used and the instrument designed to measure an acceleration of 1000 rad./sec.$^2$ with accuracy.

Using equation (5)

$$\delta = \frac{1000}{(400 \times 2\,\pi)^2} = 0.00016 \text{ radian}$$

The radius of the measuring device was approximately 3 in. so that 0.00026 multiplied by 3 = 0.00048 in., which the instrument must be able to measure with accuracy. This is a very small movement to measure accurately but it cannot be increased without increasing the size of the instrument or the fundamental error considered above.

The factor of error $\dfrac{1}{1-\left(\dfrac{\omega}{\omega_c}\right)^2}$ derived above applies only to measuring a steady sinusoidal acceleration. For measuring irregular accelerations, the factor will not be exactly the same, but the error will still be a

function of the ratio of the acceleration frequency to the natural frequency of the instrument and the factor derived above will give a good approximation to the magnitude of the error to be expected.

## Appendix II

As has been mentioned, the method used to calibrate the instrument was to rotate it at a known speed, but running free, and let a projection on the flange strike a very light, stiff spring. To rotate the instrument, it is mounted in a lathe but instead of driving it by a lathe dog a string is used having just sufficient strength to overcome friction. Then when the projection on the flange strikes the spring, the string breaks, allowing the instrument to move under the influence of the spring force and its own inertia. As shown below, this imparts a sinusoidal acceleration to the instrument.

Assumptions and symbols:
Friction negligible
Mass of spring negligible
Initial velocity $= \omega_0$
$\theta$ = Angular position of instrument
$I_2$ = Moment of inertia of instrument
$K_2$ = Spring constant (inch pounds per radian) of the spring used to stop the instrument
$t$ = time/
At $t = 0$ the projection of the flange of the instrument strikes the spring.

Then

$$I_2 \frac{d^2 \theta}{d t^2} + K_2 \theta = 0 \tag{5}$$

$$\theta = A \cos \sqrt{\frac{K_2}{I_2}}\, t + B \sin \sqrt{\frac{K_2}{I_2}}\, t \tag{6}$$

Where $A$ and $B$ are constants of integration.

At $t = 0$, $\dfrac{d^2 \theta}{d t^2} = 0$ so that $A = 0$

At $t = 0$, $\dfrac{d \theta}{d t} = \omega_0$

This gives

$$\omega_0 = B \sqrt{\frac{K_2}{I_2}}$$

or

$$B = \omega_0 \sqrt{\frac{I_2}{K_2}}$$

Then the acceleration of the instrument is

$$\frac{d^2 \theta}{d t^2} = \omega_0 \sqrt{\frac{K_2}{I_2}} \sin \sqrt{\frac{K_2}{I_2}}\, t \tag{7}$$

This equation holds only during the time when the spring is in contact with the projection on the instrument, which is from $t = 0$ to $\sqrt{\dfrac{K_2}{I_2}}\; t = \pi$. Or in other words the sinusoidal acceleration continues for only one-half a cycle.

From this it is evident that the acceleration imparted to the instrument in this manner has a frequency determined by the inertia of the instrument and the stiffness of the spring used. This frequency used for checking the instrument should be approximately the same as the frequency which the instrument is to measure. For any given frequency the magnitude of the acceleration is determined by the initial speed of rotation.

A piece of piano wire in tension was used for the spring. This gave a very light spring combined with the required high spring constant.

Fig. 7 shows the schematic arrangement for the test. Fig. 8 shows a plot of the results of this test as compared to the calculated acceleration. The agreement between calculated and test results is within the accuracy with which the oscillogram could be read.

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## ELECTRIC DISCHARGES FOR PETROLEUM PRODUCTION

Many manifestations of the potency of electricity in industrial production processes have been had and the end is not yet. A threshold type of experiment with numerous industrial possibilities was recently described before the American Electrochemical Society by Drs. Lind and Glockler. Previous experiments of Dr. Lind with radon emanations acting on ethane or other hydrocarbon gases showed that ionization resulted, one part of which brought about condensation and the formation of an oil. He then conceived the possibility of applying silent electrical discharges to the gases in the hope that similar results would occur. In the experiments made electric fields were used instead of radioactive materials, and the results were very indicative of the occurrence of similar reactions. It is a far cry from these experiments to their commercial application, but a threshold experiment of this type will be carried much further under economic urge.—*Elec. World*.

# Instability in Transformer Banks

BY KING E. GOULD[1]

Associate, A. I. E. E.

*Synopsis.—This paper considers the instability which sometimes occurs in banks of transformers supplying a capacity load when certain harmonics in the primary current are suppressed, either by the type of transformer connections or by a resonant circuit in series with the primary of the transformer, and the similarity between the several unstable circuits is pointed out.*

*Curves showing the triple-frequency voltage distortion as a function of the capacity load have been included for two of the unstable circuits. For one case, oscillograms taken during the instability are shown.*

*An explanation, substantiated by actual analyses, has been brought forward for the simplest unstable circuit, consisting of three branches connected in Y across a three-phase line with balanced, sinusoidal line voltages, with the neutral unconnected, each branch of the Y consisting of an iron-cored reactance in parallel with a capacity. This explanation is extended to the other cases, two with experimental evidence as justification, and the third by analogy only.*

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## Introduction

In 1915 Mr. L. N. Robinson published a paper[2] concerning the unstable condition which sometimes occurs when a Y-connected capacity load is supplied by a Y—Y-connected transformer bank with the secondary neutral closed but the primary neutral open. The phenomenon was evidently closely associated with the voltage distortion which occurs with this and similar transformer connections, and which has been studied by many investigators[3]. No very satisfactory explanation of this unstable condition, however, has ever been advanced so far as the author knows, and the principal object of this paper is to advance an explanation substantiated by considerable analytical proof and experimental observation.

Mr. Robinson suggested that the instability might be due to a "reversing transformer leg," but this theory has been disproved by oscillograms which show that the line voltages and currents are balanced during some of the unstable conditions, and by hysteresis loops observed during instability, which were found to remain symmetrical with respect to the two axes.

Mr. R. P. Shaw investigated this phenomenon[4] and took oscillograms and very complete data throughout both the stable and the unstable ranges of line voltage and capacity load. He also investigated a quite similar case of voltage distortion and instability which occurs when a capacity is inserted in the delta of a Y-delta-connected bank of transformers, primary neutral open. Two of his curves showing the third harmonic induced voltage as a function of the capacity load have been included in this paper.

## Experimental Work

Three identical transformers, each of 1½-kv-a. rating at 100 volts, 60 cycles, the ratio of transformation being unity, were connected Y—Y to supply a Y-connected, balanced capacity load of 12.5 $\mu f$ per phase. The secondary neutral was closed while the primary neutral was open. The transformers were supplied by a 5-kv-a., 60-cycle alternator of very good wave form for balanced loads, direct-connected to an 8-h. p., d-c. motor. Under these conditions, the transformers, emitted "grunts" or "beats" which sounded like a solid body, such as a wooden mallet, striking the laminations, and all the meters with the exception of the line voltmeter oscillated badly. The line voltage was about 200 volts, as indicated by a dynamometer type meter, and oscillated but slightly, as the change in load over a beat had but little effect upon the terminal voltage of the alternator.

This instability persisted with a wide range of capacity loads. Mr. Shaw, who worked with the same apparatus, records instability with a capacity load of as high as 40 $\mu f$. per phase. With any given line voltage, stability would occur with either a very high or a very low value of capacity, the maximum values of capacity which would produce instability being increased as the voltage was increased.

The instability was not due to the alternator supplying the transformers, as was proved by Mr. Shaw by connecting them to a large alternator, and also by taking oscillograms of the alternator field current, which was found to be perfectly regular. Mr. Robinson had also noted this instability under conditions differing widely enough to indicate that it was not due to the power source.

Fig. 1, taken from Shaw's work, shows the variation of third-harmonic induced voltage with the size of the capacity load, throughout the lower, stable range of capacity and part of the unstable range, where measurements were possible. These voltage readings were taken with a thermocouple heater element, in series with a high resistance, inserted in one corner of a delta formed with an auxiliary winding on each transformer, as shown in Fig. 2. Multiples of the third harmonic appeared in this voltage also, but they were small, as indicated by analyses of the wave form.

Mr. Shaw also experimented with a quite similar unstable condition produced by connecting the pri-

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1. Research Division, Dept. of Elect. Engg., Mass. Inst. of Tech., Cambridge, Mass.

2. Trans. A. I. E. E., 1915, p. 2183.

3. L. F. Blume, Trans. A. I. E. E., 1914, p. 735. G. Faccioli, Jour. A. I. E. E., May, 1922, p. 351. O. G. C. Dahl, Trans. A. I. E. E., 1925, p. 792.

4. M. I. T. thesis, 1924, Investigation of the Triple Frequency Distortion in Three-Phase Transformer Banks.

*Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Pittsfield, Mass., May 25-28, 1927.*

maries of the transformers as before, in Y with the neutral unconnected, and the secondaries in delta, with a capacity inserted in one corner of this delta as shown in Fig. 3. The third-harmonic induced voltage was measured across one corner of an auxiliary delta as before. As was to be expected, the capacity necessary to produce instability in this latter case was about one-third that in the Y—Y connection, as the third-harmonic voltages induced in the secondary windings add up directly to make the voltage across the capacity three

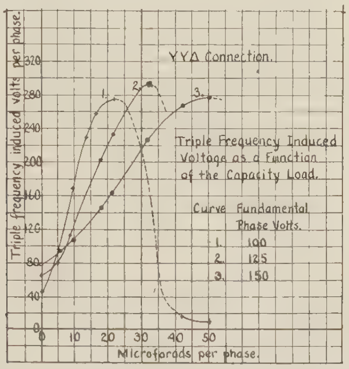


Fig. 1

times the third-harmonic phase voltage. Fig. 4, due to Mr. Shaw, shows the third-harmonic phase voltage as a function of the capacity inserted in the delta, and is similar to Fig. 1 except that the capacity has been reduced to about one-third its previous value. Mr. Shaw records that the instability commenced in the Y-delta-delta case with a capacity of from 2 to 4 $\mu f.$, which corresponds to from 6 to 12 $\mu f.$ per phase in the Y—Y—

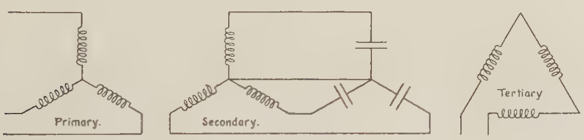


Fig. 2

delta connection. That the Y—Y connection and the Y-delta connections are essentially the same so far as the third harmonic and its multiples are concerned is evident from a comparison of Figs. 5 and 6, which represent the same circuit except that in Fig. 6 the leakage reactances of the transformer windings have been neglected.

As the removal of the primary neutral connection produced instability in an otherwise stable circuit, it seemed evident that the instability must be due to the third harmonic and its multiples, introduced by the varying permeability of the iron cores of the transformers. The existence of the Y-delta instability confirms this hypothesis.

As it was well established that the unstable condition which sometimes occurred in some star-connected transformer banks was due to the suppression of the third harmonic and its multiples in the primary current, it was conceived that by means of a series filter, the partial suppression of the harmonics in the primary current of a single-phase transformer supplying a capacity load might produce an unstable condition.

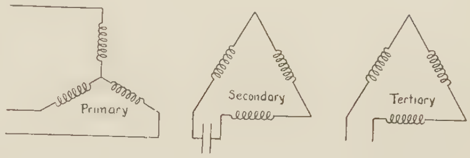


Fig. 3

Accordingly a circuit was set up as shown in Fig. 7, the transformer being one of those used in the three-phase case. The filter circuit consisted of a capacity in series with two identical air-core inductances which were mounted so that the mutual inductance between

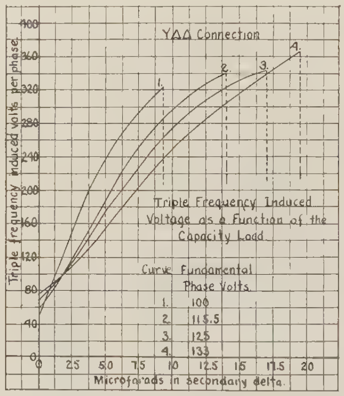


Fig. 4

them could be varied. This filter circuit was adjusted for resonance at 60 cycles, the combined impedance being 12 ohms, while the capacity and the inductance each had an impedance of 203 ohms at 60 cycles.

With this arrangement, with 110 volts at 60 cycles

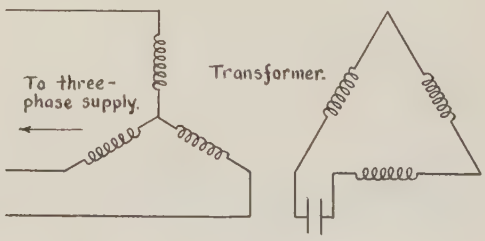


Fig. 5

impressed upon the circuit and with a capacity of 13.5 $\mu f.$ placed across the secondary of the transformer, the circuit was found to be distinctly unstable, even worse than the three-phase case, although the two instabilities were quite similar. This single-phase instability occurred over a considerable range of capacity, either

side of 13.5 $\mu f.$, but the beats seemed most violent at about this value of capacity. A great enough change of capacity in either direction would produce stability, the voltages and currents at the stable condition with high values of capacity being low, as in the three-phase case. By changing conditions, such as the voltage, frequency, or capacity load, the beats could be varied continuously from less than one per sec. to so many that nothing could be heard but a hum. In general, the beats were more violent the longer they were.

The beats were adjusted to about five per sec., so that each one included about 12 cycles, and simultaneous oscillograms long enough to show the wave form over a complete beat were taken. These are shown in Fig. 8. The oscillations were not very violent in this case, but a beat of longer period was not used because of the length of film required. It will be noted that a beat does not include an integral number of cycles.

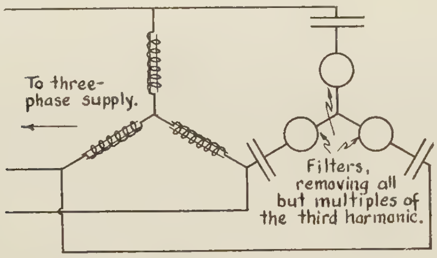


Fig. 6

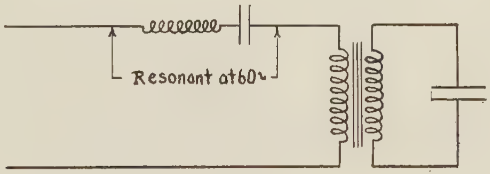


Fig. 7

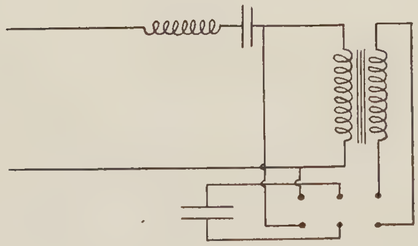

Fig. 7-A

By means of the two-dimensional oscillograph[5], an examination of the hysteresis loops of the transformer during instability was made. The hysteresis loops could be thrown upon a ground glass screen and viewed very well indeed. An attempt was made to photograph the series of loops during the unstable condition, but with no success, as the point of light traversed a given path but once, and was too faint to record this path. The loops thrown upon the screen brought out one fact—that the loops increase and decrease in size, but they always remain symmetrical with respect to the two axes.

5. E. L. Bowles, Discussion, Trans. A. I. E. E. 1923, p. 346.

It seemed possible that the unstable condition might not depend upon leakage reactance of the transformer windings, so a switch was arranged to shift the capacity load from the secondary to the primary, as shown in Fig. 7A. The unstable condition was established, and the capacity suddenly switched from the secondary to the primary of the transformer. No change could be detected in the frequency or violence of the beats. Thus it was proved that leakage reactance of the transformer windings is not a contributing cause of the instability.

In view of the fact that the single-phase instability occurred with the capacity across the primary of the transformer, it seemed probable that the unstable condition would occur if an iron-cored reactance and a capacity of the proper size were connected in parallel, and three such branches were connected in Y across a three-phase line of the proper voltage, the neutral being unconnected. Accordingly, the three transformers used before were connected in Y, the primary neutral open, and with a capacity of about 12.5 $\mu f.$ in parallel with each primary, as shown in Fig. 9. This combination was connected across a three-phase supply with a line voltage of 200 volts, at 60 cycles, and distinct beats occurred in each transformer, just as in the case with the capacity load across the secondary of the transformer.

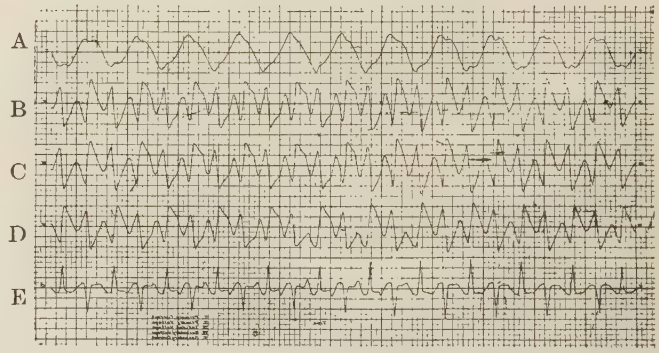


Fig. 8

A. Primary current
B. Primary voltage
C. Induced voltage
D. Secondary voltage
E. Secondary current.

## Explanation of Instability

Of the circuits found to be unstable, the one shown in Fig. 9 is most easily analyzed, as nothing but odd multiples of the third harmonic can appear in the phase voltage under stable conditions with sinusoidal, balanced line voltages, and the third harmonic and its

multiples in the exciting current must be equal in magnitude and opposite in phase to the respective harmonic currents through the capacity. All multiples of the third harmonic above the third itself seemed, from actual analyses, to be comparatively small and hence were neglected. The effect of the third harmonic in the phase voltage upon the third-harmonic exciting current was determined as follows.

A fundamental flux density of 10.2 kilogausses was assumed, corresponding to a fundamental (60-cycle) phase voltage of 100 volts. Various amounts of

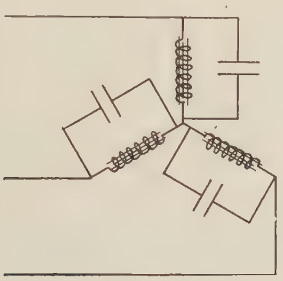

Fig. 9

third harmonic were introduced "in phase" with the fundamental; that is, so that the resultant flux wave was of the form, $A \sin w\,t + B \sin 3\,w\,t$, and the resultant flux wave was drawn. This was done with the third-harmonic flux from 12 per cent to 60 per cent of the fundamental. From Mr. P. A. Blackwell's series of hysteresis loops[6] for one of the transformers, the magnetization curve was drawn as shown in Fig. 11. From this curve, the exciting current corresponding to each resultant flux wave was determined, and each of these was analyzed for the third-harmonic current.

When the third-harmonic flux was "in phase" with

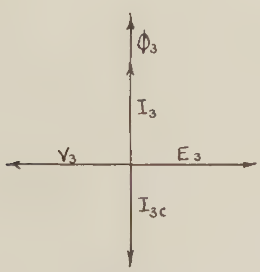


Fig. 10

the fundamental flux, the resultant flux wave was, of course, always symmetrical with respect to the 90-deg. (fundamental scale) ordinate. As there is only one value of current corresponding to each value of flux density, using the magnetization curve, the exciting current was symmetrical, also, with respect to the 90-deg. ordinate. Thus no cosine component of the third harmonic could appear in the exciting current; in other words the third-harmonic current is in phase with the third-harmonic flux. From Fig. 10, it will be seen that this is a condition which must be fulfilled if the third-harmonic exciting current, $I_3$, is to be in phase opposition to the current through the capacity. In Fig. 10, $\phi_3$ is the third-harmonic flux which produces the induced voltage $E_3$, while $V_3$ is the third-harmonic impressed voltage which causes the current $I_{3c}$ to flow through the capacity. The resistance and leakage reactance of the transformer winding are neglected.

Thus it will be seen that the phase relation of the third-harmonic exciting current remains correct if the magnetization curve is used. Moreover, the third-harmonic exciting current increases more rapidly than the third-harmonic current through the capacity, after the maximum flux density becomes high, so that the two will become equal in magnitude. Hence the saturation curve cannot produce instability by making

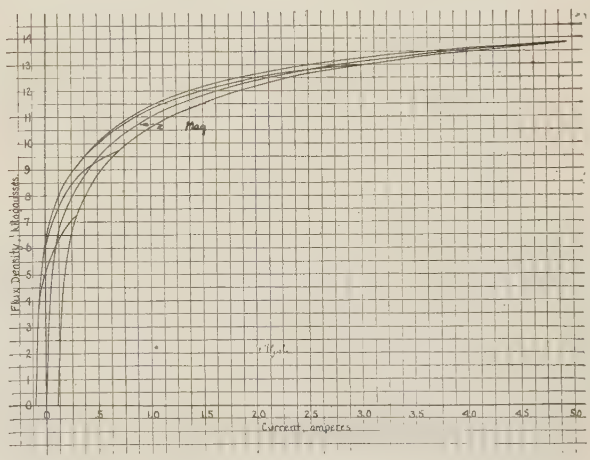


Fig. 11

it impossible for the two third-harmonic currents to become equal in magnitude and opposite in phase.

As the use of the saturation curve would not indicate instability, the exciting current was determined from the hysteresis loops shown in Fig. 11 and taken by Mr. P. A. Blackwell for one of the transformers. For any desired maximum flux density, a loop similar in shape to the ones shown was interpolated It was assumed that each secondary hysteresis loop was thin enough to practically coincide with the portion of the main hysteresis loop where it started. Loops taken by Mr. W. M. Gilman[7] indicate that this assumption introduces but little error.

The third-harmonic flux density was varied, in steps of 12 per cent, from zero to 60 per cent of the fundamental flux density, as before, but each value of third harmonic flux density was introduced at 20-deg. (fundamental scale) intervals. The resulting exciting current waves were analyzed for the third harmonic by means of

6. M. I. T. thesis, 1924, Unstable Effect in Three-Phase Transformer Bank with Capacity Load.

7. M. I. T. thesis, 1925, Quantitative Analysis of Transformer Harmonics.

the Woodbury analyzer[8], which was quite satisfactory for waves with a cyclic length as long as was used, 12 inches. Fig. 12 shows a sample wave, the third-harmonic flux being 48 per cent of the fundamental, and introduced so that the resultant flux wave was of the form, $[A \sin w\,t + 0.48\,A \sin 3\,(w\,t + 20°)]$.

The magnitude of the third-harmonic exciting current, $I_3$, was plotted against the third-harmonic flux, $\phi_3$, for given angular displacements between the fundamental and the third-harmonic fluxes, as shown in

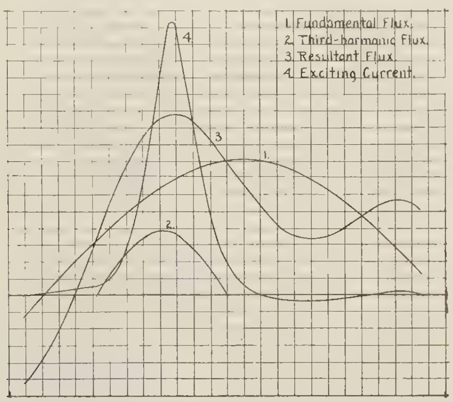


Fig. 12

Fig. 13. This angle, which we shall call $\theta_{3\phi}$, is the fundamental angle by which the zero point of the third-harmonic flux wave lags the zero point of the fundamental flux wave, both zero points being those at which the slope is positive. Thus the flux wave is expressed as $A \sin w\,t + B \sin 3\,(w\,t + \theta_{3\phi})$. The intersections of the curves of $I_3$ against $\phi_3$ with a line which repre-

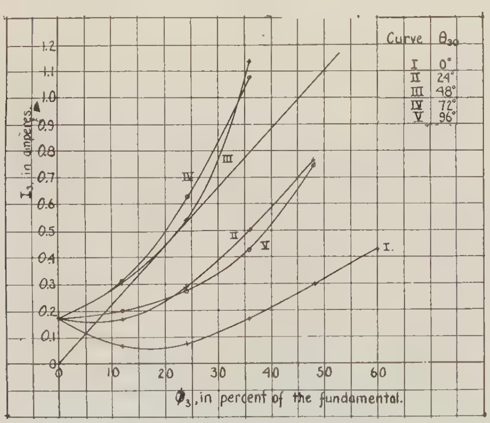


Fig. 13

sented $I_3$ against $\phi_3$ for a capacity of 6.5 $\mu f.$ gave values of $\phi_3$ and $\theta_{3\phi}$ at which the magnitude of the third-harmonic exciting current was correct for this value of capacity. These values of $\phi_3$ and $\theta_{3\phi}$ were plotted as shown in Fig. 15, curve I.

The angle, $\theta_{3I}$, by which the third-harmonic current lags the fundamental flux (that is, the fundamental angle by which zero point of the third-harmonic current lags the zero point of the fundamental flux, both zero points being those at which the slope is positive), for constant values of third-harmonic flux, was plotted against the lag of the third-harmonic flux behind the fundamental flux shown in Fig. 14. As this third-

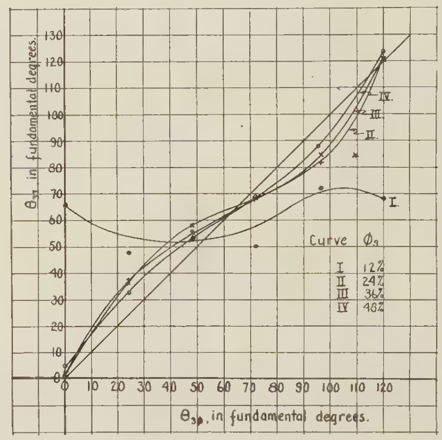


Fig. 14

harmonic current must be in phase with the third-harmonic flux in order to be in phase opposition to the third-harmonic current through the capacity, the angles $\theta_{3I}$ and $\theta_{3\phi}$ must be the same so that the intersections of the curves of Fig. 14 with a straight

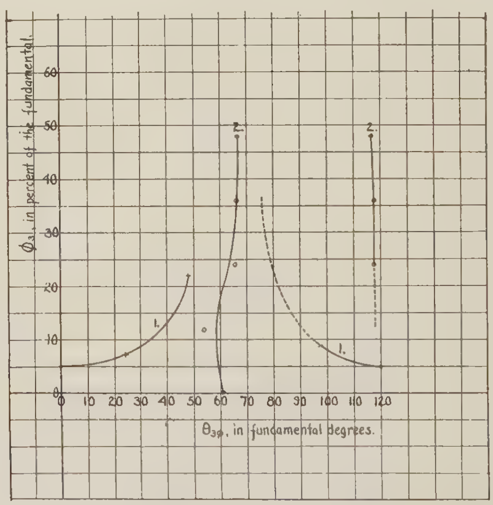


Fig. 15

line through the origin and with a slope of unity gave values of $\phi_3$ and $\theta_{3\phi}$ at which the phase of the third-harmonic exciting current was correct. The locus of the point at which the phase was correct is shown in Fig. 15, Curve 2.

It should be noted that the part of Curve 2 which lies at $\theta_{3\phi}$, equal to about 117 deg., is actually discontinuous downward, stopping at a value of $\phi_3$ somewhere between 12 per cent and 24 per cent. The portion between these two points is shown dotted, as it is not known

8. F. S. Dellenbaugh, Jr., A. I.E. E. Jour., Jan. 1923. p. 58.

exactly where the curve stops. For each value of $\phi_3$ below 12 per cent, there is only one value of $\theta_{3\phi}$ at which the phase of $I_3$ is correct. Also, it should be noted that the "phase correct" curve at $\theta_{3\phi}$ equal to about 60 deg. approaches 61 deg. as a limit, $\theta_{3\phi}$ at $\phi_3$ equal to zero being indeterminate.

It will be seen from Fig. 13 that the magnitude of the third-harmonic exciting current is never correct for values of $\theta_{3\phi}$ between 48 deg. and 72 deg., as all the $I_3 - \phi_3$ curves for this range of $\theta_{3\phi}$ lie entirely above the straight line which is drawn for the 6.5-$\mu f$. condenser. As this straight line is tangent to the curve for $\theta_{3\phi}$ equal to 48 deg., the left-hand "magnitude correct" curve becomes vertical at this value of $\theta_{3\phi}$, and for increasing values of $\phi_3$, $\theta_{3\phi}$ will decrease. Similarly, the right-hand "magnitude correct" curve becomes vertical at some value of $\theta_{3\phi}$ greater than 72 deg., and for increasing values of $\phi_3$, $\theta_{3\phi}$ increases. The dotted line added to the "magnitude correct" curve is to show that it is definitely known that the curve never crosses a vertical line erected at $\theta_{3\phi}$ equal to 72 deg.

Thus, in Fig. 15, there is no intersection between the "magnitude correct" and the "phase correct" curves, which means that with a fundamental phase voltage of 100 volts and a capacity of 6.5 $\mu f$. per phase, the magnitude and phase of the third-harmonic exciting current never become correct at the same time, at least over the range of third-harmonic voltage considered; that is, up to about 150 per cent of the fundamental. This seems a reasonable cause of the instability, as under stable conditions the third-harmonic exciting current and the third-harmonic current through the capacity must be equal in magnitude and opposite in phase.

It would seem probable that with higher values of third-harmonic voltage, no intersection of the "magnitude correct" and "phase correct" curves would occur. In Fig. 13, it looks as though the straight line for 6.5-$\mu f$. capacity would not intersect the $I_3 - \phi_3$ curves for $\theta_{3\phi}$ near 120 deg., which would mean that no intersection would occur along the "phase correct" curve near $\theta_{3\phi}$ equal to 120 deg. Moreover, analyses of oscillograms and Mr. Shaw's measurements have not shown a third-harmonic voltage so great as 150 per cent of the fundamental for this value of capacity.

If, in Fig. 13, the straight line is given a greater slope, —that is, the capacity is increased far enough,—this line will intersect the $I_3 - \phi_3$ curves corresponding to $\theta_{3\phi}$ in the range about 60 deg., and hence an intersection of the "magnitude correct" and the "phase correct" curves would occur along the "phase correct" curve near $\theta_{3\phi}$ equal to 60 deg. Moreover, no matter how much more the capacity is increased, there will always be an intersection in Fig. 15, with $\theta_{3\phi}$ near 60 deg., and hence always a stable point.

If the capacity is decreased far enough, the $I_3 - \phi_3$ line for the capacity, in Fig. 13, will intersect the $I_3 - \phi_3$ curves for $\theta_{3\phi}$ near 117 deg., at values of $\phi_3$ great enough to produce an intersection of the "phase correct" and "magnitude correct" curves near $\theta_{3\phi}$ equal to 120 deg. At very low values of capacity, the straight line, Fig. 13, becomes tangent to the curves for $\theta_{3\phi}$ equal to 120 deg., and of course for smaller capacities than this, the magnitude never becomes correct, according to the curves. For such a small capacity, however, higher multiples of the third harmonic may have appreciable effect upon the third-harmonic exciting current, or there may be instability which, due to the small current through the capacity, is unnoticeable.

According to the analysis described above, there appears to be a wide range of capacity at which the unstable condition occurs, although an insufficient number of $I_3 - \phi_3$ curves have been plotted to determine the limits of this range of capacity. Experimentally it was found that 8.5 $\mu f$. per phase would produce instability, the fundamental phase voltage being 100 volts at 60 cycles, while with four $\mu f$. per phase no instability could be detected. Lack of suitable capacity prevented more accurate determination of the range of instability. According to the curves of Figs. 13 and 15, it seems likely that instability would occur at four $\mu f$., which indicates that the lower limit of capacity which will produce instability is actually greater than that indicated by this analysis, due possibly to the stabilizing effect which is possible by the introduction of odd multiples of the third harmonic in the phase voltage.

As the circuit analyzed is equivalent to a Y—Y-connected transformer bank supplying a Y-connected capacity load, with the secondary neutral closed but with the primary neutral open, neglecting the leakage reactances of the transformer windings, and as experiment has shown that the instability is essentially unchanged by switching the capacity load from the primary to the secondary, (taking due account of the ratio of transformation), the above explanation should apply to this latter type of circuit also. Moreover, as the circuit analyzed is equivalent, so far as the third harmonic and its multiples are concerned, to a Y-delta-connected bank of transformers with a capacity inserted in one corner of the delta, and with no primary neutral, again neglecting the leakage reactances of the transformer windings, the above explanation seems valid in this case also. Figs. 5 and 6 illustrate the similarity of the circuit analyzed and the above $y$-delta connection.

## Results and Conclusions

1. An unstable condition, quite similar to the one which may occur in some star-connected transformer banks, may be produced with a single-phase transformer supplying a capacity load, by partial suppression of all higher harmonics in the primary current by means of a filter circuit. Stability will be produced if any of the conditions, as voltage, frequency, or size of the capacity load, are changed far enough in either direction.

2. Hysteresis loops traced upon a ground glass screen by the two-dimensional oscillograph during this unstable condition increased and decreased in size, but always remained symmetrical with respect to the two axes.

3. Both the single-phase and the three-phase instability existed with the capacity load connected across the primary. Thus leakage reactance cannot be a contributing cause of the instability.

4. Under the cause of the three-phase instability developed herein, the saturation curve cannot alone produce instability. Hysteresis, as well as non-linearity of the magnetization curve, is necessary.

5. There is considerable evidence that the three-phase instability (Y-connected branches of capacity and iron-cored inductance in parallel, with neutral unconnected) is due to the inability of the third harmonic and its multiples in the phase voltage to adjust themselves so as to make the third-harmonic exciting current and its multiples equal and opposite to the respective harmonics in the current through the capacity. As these conditions must be fulfilled during steady-state operation, this failure constitutes a reasonable cause of the instability. Hysteresis is necessary to produce instability, as mentioned above; non-linearity of the magnetization curve alone is not sufficient.

It has been shown, by drawing the exciting current wave from the hysteresis loops and the voltage waves, that when the iron-cored inductance and a certain capacity are connected in parallel, with three such branches connected in Y and with no neutral connection, across a three-phase supply with a certain value of balanced, sinusoidal line voltage, the third-harmonic phase voltage cannot adjust itself to make the third-harmonic current through the inductance equal and opposite to that through the capacity. This analysis neglects all multiples of the third harmonic above the third itself.

The lower limit of capacity which will produce instability, as indicated by this analysis, is somewhat less than the actual limit as indicated by experiment. This would seem to be due to the stabilizing effect produced by the introduction of higher odd multiples of the third harmonic in the phase voltage, these harmonics appearing only in order to produce stability.

6. The above explanation covers the instability which occurs when the capacity is connected across the secondaries of the transformers, Y—Y, with no primary neutral connection, as the two circuits are equivalent, neglecting leakage reactance of the transformer windings. It also covers the case of Y-delta-connected banks, with the primary neutral unconnected, when a capacity is inserted in the secondary delta, as this circuit is similar, in so far as the third harmonic is concerned, and neglecting leakage reactances, to the circuit for which the analysis was made.

7. It seems probable, although no proof has been advanced, that the single-phase instability is due to the inability of all the harmonics in the voltage impressed upon the inductance and capacity in parallel, to adjust themselves so as to make each harmonic in the exciting current equal and opposite to the corresponding harmonic current through the capacity, assuming that the filter circuit is perfect. The cause of this instability then becomes quite analogous to that of the three-phase case.

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## TESTS INDICATE RADIO WAVES PENETRATE EARTH AND ROCK

Tests conducted by the United States Bureau of Mines, Department of Commerce, in a Colorado metal mine indicate strongly that radio waves will penetrate 500 feet or more of rock strata. These preliminary experiments were observed by Dr. A. S. Eve, Director of the Department of Physics, McGill University, Montreal, Canada, who is conducting a study for the Bureau of Mines of the possibilities of various methods of geophysical prospecting for the location of underground mineral deposits.

The experiments participated in by Dr. Eve were conducted with a superheterodyne set with nine electron tubes in the Caribou mine of the American Mining and Prospecting Company, at Caribou, Colorado. The first test was held at a depth of 220 feet, where, by means of a loop, a strong and clear reception was obtained of a musical concert given at Denver, 50 miles distant. The evidence pointed strongly to the conclusion that this clear reception was due to the penetration by the radio waves of the solid rock strata, although there was a remote possibility that the reception was obtained through shafts and cross-cuts, toward which, however, the loop did not point. The nearest metal conductors, iron rails, were 66 feet away.

The next series of experiments was conducted at a depth of 550 feet, when "mushy" reception was obtained from Denver. This type of reception was, however, as good as could be obtained above ground at the time of making the test, the night being unfavorable for general radio reception. This series of tests was conducted at the end of a cross-cut reached with many turns, and 200 feet from the main shaft. A pipe came down the shaft and followed the tunnel up to 80 feet from the point of observation.

In previous experiments conducted by the Bureau of Mines at its Experimental Mine near Pittsburgh, Pa., it was at first concluded that radiation and induction would penetrate rock for considerable depths. Subsequent investigations have shown that in every case the transference of radiation was by some conductors in the mine, electric wires, pipes or rails, all of which abound in modern mines.

It is felt that further investigations should include a comparison of the penetration of radio waves greater and less than a wave length.

# Recent Improvements in Large Induction Motors

BY D. F. ALEXANDER*

Associate, A. I. E. E.

***Synopsis.**—Like that of many other rotating electrical machines, the development of the large induction motor has been a steady and an interesting progression. From the first induction motor to the present product has been a long step, marked by the analytical ability of many capable engineers, and accompanied by continual improvements in construction, some of which are reviewed in this paper. To describe the advancement in this type of motor to its present state, it has been necessary to follow some trends in development from their beginning; thus not all of the improvements mentioned in this paper can be called recent, as time in the rapidly advancing electrical industry is measured. The paper, taking up briefly the subjects of ventilation, insulation, coil design and bracing, collectors, bearings, and manufacturing improvements, should be of interest to the many users of the large induction motor.*

## INTRODUCTION

THE induction motor is one of the least spectacular yet most serviceable of man's electrical power servants. The evolution of this type of motor, in common with that of other electrical machinery, has been marked by a steady improvement in the application and use of the various materials of which the motor is made. Although the general arrangement has changed but little in the past twenty years, there has been a continuous attention to those details which contribute to reliability, to long life, and to satisfactory performance. During that time, improvements in the electrical design and in distribution of materials have given us induction motors having but one-third to one-half the weight per horse power of those first produced.

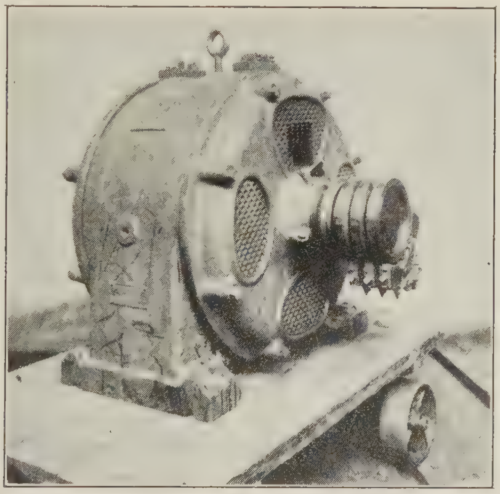

FIG. 1—EARLY DESIGN OF INDUCTION MOTOR

In the early motors the heavy construction gave the advantage of a high thermal capacity; this was of little value on sustained overloads, however, and in any case there was always the danger to the insulation from the presence of hot spots in embedded portions of the windings. The more open type of construction in the modern motor, with a more systematic arrangement system of ventilation, greatly improves reliability in this respect. Consistent use of mica insulation and improved processes of dipping and baking have given further dependability under an increasing variety of applications.

## VENTILATION

The gradual decrease in motor weights for a given rating has resulted largely from improvements in motor ventilation. Since a motor is sold on the basis of the maximum permissible temperature rise of its least durable part, *i. e.*,—the insulation,—it is obviously an advantage to have as nearly uniform temperatures as possible throughout the heat-generating parts for minimum temperature rise. With this carried to reasonable limits, the temperature rise may be still further reduced by an increase in the volume of air passing through the motor. Modern motors are distinguished from older motors by the open and well-ventilated construction of all active parts.

In the first type of induction motor to be produced on a commercial scale in this country, less attention was paid to the distribution of the losses than to the importance of obtaining a motor having the proper performance characteristics. There were no strict temperature specifications to be met, the only requirement being that the insulation would stand up under operating conditions.

In these motors, and in the types immediately succeeding them, little opportunity was given for effective ventilation other than by natural convection and radiation from the surfaces. There were no definite paths for the ventilating air as in modern motors; there were neither air ducts, blowers, nor ventilating openings in the frame periphery. In the larger motors, which used partially closed primary slots and "pushed-through" windings, the location of the end connectors and their size prevented a free passage for air. In modern types of winding, the ventilation of the end turns is of great importance.

Later types were greatly improved, as the benefits from the proper use of ventilating air became apparent.

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*Presented at the Regional Meeting of District No. 2 of the A. I. E. E., Bethlehem, Pa., April 21-23, 1927.*

The primary slots were made so that completely form-wound or "diamond" coils could be placed in them; the end turns of this type of winding are symmetrical and easily ventilated by leaving an air space between coil sides; see Fig. 2. Air ducts were placed at intervals in the core and openings were made between frame ribs for exit of the ventilating air.

Although the rotor ventilating-duct fingers were quite effective as fans, the addition of blower vanes on the rotating part proved to be of benefit. The air leaving the blower vanes passed directly through the primary coil ends, cooling them to such an extent that the maximum copper temperature at the center of the core was considerably reduced, due to the rapid conduction of heat from the middle of the coils to the ends. The brackets, or endbells on a pedestal-type motor, were closed about the primary coil ends and shaped in such a manner as to direct the cooling air most effectively. Openings between the punching support-ribs allowed this air to escape along the back of the built-up laminations, further cooling these parts, and thence out through the frame openings.

In general, all possible restriction is removed from the path of the ventilating air in modern large induction

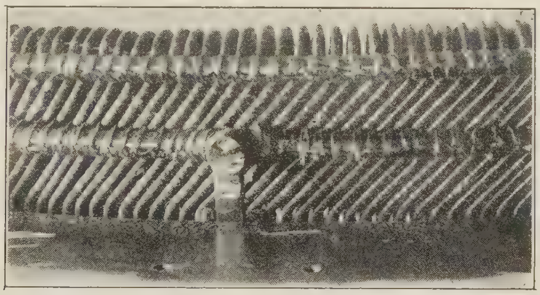


Fig. 2—Primary End-Turns of a Modern Induction Motor
Showing ventilating spaces and coil bracing

motors. The spider and frame are made of a skeleton design, supporting the laminations upon transverse ribs between which are large openings. Shrouds and air shields are frequently used to confine the air in the proper channels. The general scheme of ventilation has not been changed in the past few years, but improvements have resulted from attention to constructional arrangement and from a better knowledge of the motor losses and their effective dissipation to the cooling air.

Fundamental differences in electrical-design proportions and in mechanical construction make the ventilation arrangement in large induction motors unlike that found in other types of motors or generators.

Large turbo generators, with a large ratio of rotor length to diameter and with a concentration of losses in a comparatively small volume, require some form of axial, or of combined axial and radial, air flow. In the ordinary form of d-c. or synchronous a-c. machinery, the salient poles on either stationary or rotating part alter ventilating conditions in comparison with induction motors, which have a close confinement of air in both stator and rotor. Furthermore, the air-gaps are large, and the projecting poles, when placed on the rotor, act effectively as fans. The location of the losses in these machines favors their dissipation, and considerations of reactance and loss balance in the synchronous apparatus do not require the many coils and narrow teeth of the induction motor. These factors make a contrasting problem between the ventilation of the induction motor and that of other machines.

Large induction motors are frequently applied in locations which prohibit the use of an open motor. Moisture, dirt, dust, acid fumes, or other impurities which would damage the insulation, make it necessary to enclose the motor partially or totally. To protect against falling particles, a simple canopy cover or hood of sheet steel may be sufficient. For further protection, complete enclosure of the motor with forced air ventilation has become increasingly popular. In this case, the air led to the motor may be thoroughly cleaned and cooled, and interruptions due to insulation failure thereby minimized. The cooled air also permits heavier temporary overloads than would be possible otherwise.

## Insulation

The successful operation of all electrical machinery depends to a great extent upon the character and quality of the insulation used in its manufacture. Insulating materials consist of mica, asbestos, papers, cloths, varnishes, and other materials less well known. It is easily recognized that the insulation, considered from a physical viewpoint, is inferior to the durable metal parts entering into the construction of the motor. In spite of this fact, the design of electrical machinery has been so modified in the past that the inherent weaknesses of insulating materials have been favored, resulting in machines which have operated for many years with satisfaction.

The last years however, have shown a decided tendency on the part of manufacturers, to secure a more basic knowledge of the physical properties of insulating materials. Among other things, this has enabled the designer to obtain more compact insulation on the coils, thus improving the transfer of heat from copper to cooling air ( a decisive factor in reducing the occurrence of hot spots in the windings). A more scientific application of the materials and refined processes of manufacture, together with a more complete understanding of conditions arising in motors, such as surges, has resulted in further improvements.

*Duties.* The function of insulation is primarily to prevent current conduction between points which are at a difference of potential; in some instances the insulation also serves as a mechanical support. In order that these duties may be fulfilled, insulating materials should have certain electrical, mechanical, chemical, and thermal properties. The most important of these properties is the ability of the insulation

to withstand potential stress; of importance, also, are the ease of application, thermal conductivity, permanency, and resistance to abrasion, moisture, oils and acids. Combinations are made to obtain the greater advantages of two or more insulating materials: mica is combined with reinforcing paper, cloths with varnish treatment, and so on.

*Mica.* Of the insulating materials available, mica is probably the best. Its beneficial use, however, requires a careful consideration of its capabilities and limitations. The chief advantages of mica are its high dielectric strength and resistance to high temperatures, making it suitable for the voltages and temperatures encountered in electrical machinery. In addition, it has a certain amount of resilience and does not absorb moisture.

Mica has poor mechanical strength, a disadvantage which must be compensated for by building up the mica splittings into sheets with a suitable bond, to secure the increased strength and flexibility necessary. The use of built-up mica coil wrappers results in a uniform and continuous wall of insulation comparatively solid and free from air pockets, a condition which offers the least resistance to heat flow.

For large motors, mica is used on the straight part of the motor coils, that is, the part which is embedded in the slot. The quality of long life at high temperature is here used to best advantage, for this part of the insulation is subjected to the maximum temperature in the machine. Mica gives a very high factor of safety for this part of the coil. The ends, which are well cooled, do not require mica; treated cloths and tapes are more easily applied, and are less expensive.

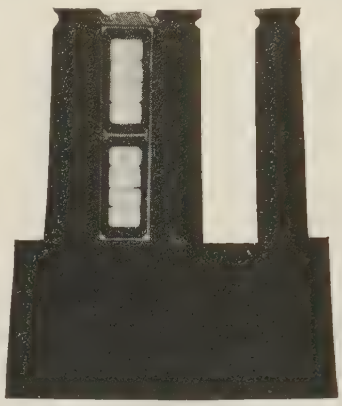
The quality of built-up mica as an insulation material has undergone a continual improvement since it was first introduced. The manufacturer has cooperated with the producer to secure the proper grade, and to improve methods of packing and shipping so that the material might be fully protected while in transit. Bonds have been studied extensively, with the result that built-up mica now has flexibility and strength together with its inherent insulating and high temperature-resisting qualities. The introduction of machine methods and processes has resulted in a more uniform and consequently a more reliable product. More exacting test methods, together with these manufacturing improvements, combine to produce more satisfactory motor windings, both with regard to continuity of service and to life of the insulation.

*Fibrous Materials.* Under this head are included the fabrics and papers in the various forms used for insulating the motor windings.

The insulation on the coil-ends consists of layers of treated cloth tape, followed by a single layer of cotton tape covering the entire coil. The varnishing of the individual layers effectively prevents the penetration of dust, dirt and moisture. The final layer of cotton tape serves to protect and to bind the insulation in place; the coil is then dipped in a suitable grade of insulating varnish. After draining, it is placed in an oven and baked. This process is repeated as many times as is necessary. Fibrous materials absorb moisture very readily, but by treating the coils in the above manner, these materials are rendered moisture proof. Great improvements have been made in connection with moisture-proof treatment processes for large induction motors.

Paper insulation is employed in motor construction. Various forms of insulating paper strips may be used in forming the coils; a slot liner of tough, flexible paper is combined with treated cloth to protect the coil from injury when being placed in the slot.

*Varnishes.* The use of completely formed and insulated coils has been an essential factor in improving



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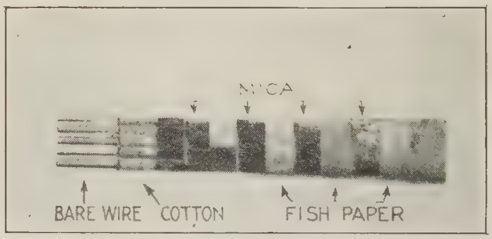



B

Fig. 3—Stator Coil and Slot and Stator Coil Insulation

the reliability and life of motor windings. The insulation consists of mica and fibrous materials as previously mentioned, treated with varnishes or gums to overcome their natural tendency to absorb moisture. The addition of moisture-resisting compounds improves the properties of the treated materials as insulators, tends to prevent action from oils or acids, and improves the thermal conductivity—all of which are desirable characteristics.

In general, insulating varnishes are "air-dried" or "baked" on the parts to which they are applied, depending upon the application and the size of the motor. Varnish processes are used in three stages of large induction motor manufacture:

1. On the formed coil before wrapper or tapes are applied,

2. On the completed coil,
3. On the completely wound stator or rotor.

For the ordinary application, the formed stator coil is given varnish treatments (to seal against moisture and to facilitate conduction of heat). The process consists of drying, dipping, draining and baking. Drying is carried out at the proper oven temperature, and is of sufficient duration to completely dry out the coils without injuring the cotton covering on the conductors. The coils are dipped while hot, to prevent re-absorption of moisture. The consistency of the varnish is carefully maintained so that the penetration may be complete. By permitting the coils to drain, the excess varnish is removed, giving a uniform coating to the coils and allowing the baking to be done quickly and efficiently. The temperature and ventilation of the oven are regulated so that the varnish is dried throughout. The above process is repeated as many times as necessary.

On the largest machines, and especially those for high voltage, the stator coils are vacuum impregnated; that is, the coils are dried under a partial vacuum to remove the moisture, after which a compound is forced into them under pressure. This promotes absolute penetration, filling all voids, with consequent reduction of corona and improved heat conduction.

The use of varnishes on the completed coil is much the same as that for the interior of the coil, and has been discussed in connection with fibrous materials.

After assembling all the coils in the slots, and making the connections, two or more coats of baking varnish are applied to the complete windings. These seal the connections and coils in the slots, filling up all small cracks and pores in which dirt or moisture might accumulate. The varnish is chosen so that upon drying it will be elastic, and have a fairly hard and glossy finish, resisting injury and providing a surface from which dust may be removed easily. In addition, the shedding of water and oil takes place much more readily.

The extensive applications of varnish and its development in connection with the insulation of electrical machinery is no doubt one of the great outstanding improvements of the insulation art. Originally, varnishes served more as a finish or as a mechanical protection, rather than as an insulator. Under operating conditions, the varnish and insulation became hard and brittle, making coil repair a difficult problem. Varnishes are now produced which are much more durable, flexible, and of a high insulating quality.

The control of temperatures, varnish consistency, times of baking and the ventilation of ovens, together with more exact manufacturing specifications for these factors, has materially improved insulation, in addition to giving a uniform and consistent product.

*Research on Temperature and Vibration.* When coil insulation is continuously subjected to high temperatures it is well known that its life is considerably shortened. Numerous studies of the effect of temperature upon insulation have been made from time to time, and valuable information has been obtained. From these tests it has been observed that mica is capable of withstanding high temperatures much more satisfactorily than fibrous materials. This has led to the extensive use of mica for the slot portion of coils. The effect of repeated thermal expansions and contractions upon insulation has been investigated to some extent.

A study of the vibration and movement of coils has been made recently, with a view towards eliminating possible cracking and disintegrating of the insulation. In addition, extended heat-vibration tests in which the whole motor was caused to vibrate, have been concluded. These tests confirm operating experience that the life of insulation depends not only upon the temperature at which it is operated but also, to a great extent, upon the mechanical disturbance to which it may be subjected.

Further studies along these lines are being conducted, to obtain a more exact knowledge of insulating materials under specific operating conditions, and thus a corresponding improvement of the electrical machines to which they are applied.

*Improved Methods of Testing.* Standard tests require the application of a high voltage of normal frequency between the windings and the core or frame. For further protection, the manufacturer applies this test at various stages of construction in order to detect any faults that may arise as the work progresses. Although no standard rules are given for the testing of insulation in the same circuit, such as from one turn to another, one electrical manufacturing company has realized the need of such a test and has accordingly developed a means of applying high voltage between the turns of a coil. Until very recently, insulation was tested between turns at low voltages and detected short circuits only where there was contact between conductors, but did not detect weak or damaged insulation where there was no actual contact.

Briefly, the improved method consists of applying a voltage at high frequency to the terminals of the coil, and because the voltage drop across the terminals is proportional to the frequency applied, practically any desired voltage between turns can be obtained, provided the frequency is sufficiently high.

In general, it can be said that this method of testing has had a favorable influence on the design of insulation. It shows that in some of the older designs insufficient insulation was used, while in others the insulation was more liberal than required, and it also detects insulation injuries which have developed during the coil forming operations. High frequency tests simulate the uneven voltage distribution which occurs with surges and line disturbances, enabling the designer to correctly proportion the insulation to meet these conditions.

The direct result of the high frequency test has been

the elimination of weak or defective coils which might otherwise have caused trouble in service.

## Coil Design

To obtain high power factor and to reduce iron losses as much as possible, early induction motors followed the designs for large alternators, and adopted the partially closed slot for both primary and secondary windings. With this type of slot, the primary coils for the smaller motors could not be fully formed before being placed in the motor; the strands were inserted individually. A slot cell and treated tape on the end turns were depended upon for proper insulation. The larger motors used a U-shaped coil, pushed through the slots from one end, then formed to shape and connected. For coils of many turns, this made the connections difficult to make and to insulate; it was very difficult to make repairs, and a single coil breakdown would generally require a completely rewound primary.

After using the partially closed slot for several years, the operating public decided that less expert skill should be necessary when making repairs, and that it would be preferable, to a certain extent, to sacrifice operating characteristics in favor of the open type of primary slot. The open slot allows the use of completely form-wound coils, treated, dipped and baked before assembly in the machine. The coils are interchangeable, except that outside coils on each phase-group have somewhat more insulation on the ends than coils within a group.

In attempting to combine the advantage of the open and the closed slot constructions, various forms of magnetic wedges were tried. The many difficulties in obtaining a metal wedge which would serve the desired purpose and stay in place proved to be too great. Today the fiber or hardwood wedge is used exclusively for open slot stators.

Although the primary slots have been changed, the secondary slots have remained of the partially closed type. There are several reasons for this aside from the decreased magnetizing current and iron losses resulting from the arrangement:

1. The rotor circuits operate at a very low frequency compared to the stator circuits, which are always at line frequency. This permits the use of a few deep bars per slot instead of many small wires. The solid straps on wound rotors may be insulated easily before insertion in the motor, as will be explained.

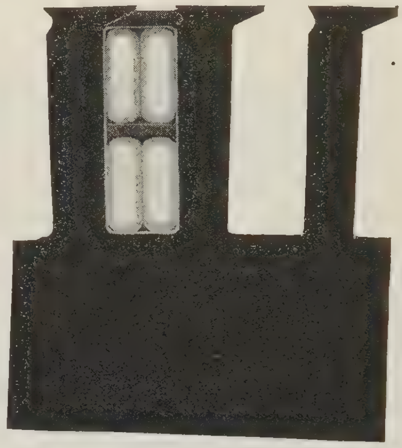
2. Centrifugal stresses require greater strength and the overhanging tooth tips retain the rotor conductors to better advantage.

3. The stator windings have a fixed voltage applied to them, so that various numbers of coil turns and degrees of chording must be used to satisfy induction and voltage conditions. For wound-rotor motors, the rotor voltage is not so fixed, and four straps per slot are used in all standard cases. These are full pitch windings.

4. The use of strap "wave" windings for wound rotors greatly simplifies the connections, and gives a symmetrical arrangement of leads which contributes to a good running balance.

For the same reasons which brought about the use of pulled coils on stators, an improvement was made in the rotor coils. These were completely formed, and each strap insulated before being placed in the rotor

A



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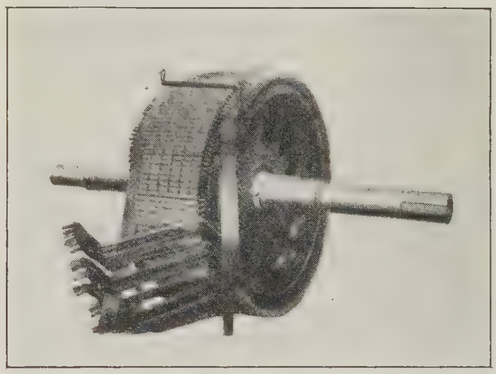

C

Fig. 4—A. Typical Rotor Coil
B. Section Through Rotor Coil and Slot
C. Partially Wound Rotor

slots. Fig. 4 shows a typical coil for a retrogressive "wave" winding, and a cross-section of the rotor slot with coils in place.

The older "shoved-through" rotor winding involved bending the coils after these had been put in place, to form the "diamond" on the ends. This necessarily strained the insulation near the ends of the coil, and

although such strain might not be readily detected by factory inspection and test, it would eventually come to light after the motor had been exposed to dust and dirt in service.

The removal of a damaged bar was difficult, since it was necessary to straighten out a considerable number of adjacent bars before any bar could be withdrawn. This involved great danger of injury to the insulation, especially after the insulation had become old and hardened; complete new rotor windings were often necessary.

The improved coils, fully formed and insulated, are placed in the slots in the same manner as for primary coils, see Fig. 4; there are no forming operations necessary for the replacement of coils. This facilitates inspection and repair. Soldered joints on rotors are a necessary evil, but formed strap windings use connectors on one end only, or one-half the number of connectors required for the "shoved-through" type.

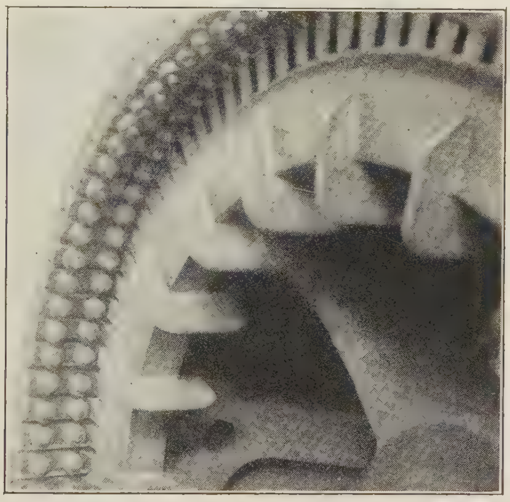

Fig. 5—Old Design of Squirrel-Cage Rotor
Showing bolted-on bars and cast blower vanes

The squirrel-cage rotor, with the simple type of bar winding, has been made in many forms, but has not been radically changed in the past twenty years. The most interesting change was made when all insulation was removed from rotor bars as unnecessary. A larger conductor could be placed in a given slot. The all-metal rotor became even more simple and sturdy than before, and on the very small rotors, which are outside the scope of this paper, the windings, end-rings, and blowers are all made of alloy and cast in place with one operation.

Blowers for squirrel-cage rotors formerly consisted of small and comparatively ineffective vanes, cast as part of the end-rings; see Fig. 5. An improvement was made when separate sheet-metal fabricated blowers similar to those on wound rotor motors, were used on rotors of moderate speed. Shrouds were conveniently added to these blowers, increasing their efficiency of delivery.

Originally, the rotor resistance rings were secured to the bars by bolts, nuts, and lock washers. These occasionally came loose and caused trouble. An improvement was made when a process of brazing was employed, using silver solder, and making the windings as solid as though made of one piece.

The end portions of induction motor coils are subjected to considerable vibration and these parts must be well secured to prevent undue chafing of the insulation or distortion of coils ends. The rotor coils, placed upon a flat surface and held securely with banding wire, require no further bracing, but the stator coils must be firmly held to a supporting ring or brackets as shown in Fig. 2. For very long coil extensions, small blocks of insulation are often placed on the diagonals, holding the adjacent coil-sides tightly together at several places, yet allowing the passage of ventilating air between them. For certain applications, such as for full-voltage starting, normal bracing requirements are considerably exceeded, and special coil bracing must be used. Investigation has shown improved methods of tying and bracing the coil ends, so that all squirrel-cage motor windings can now be adapted to full-voltage starting when this is required.

## Full-Voltage Starting

For certain applications, notably for power station auxiliaries, simplicity of operation and reduction of first cost recommend squirrel-cage motors which can be started at full line voltage. With attention to coil bracing, standard squirrel-cage motors may serve the purpose, provided the starting current is not too high and that reduced full-load efficiency is acceptable for motors requiring high starting torque. Where low starting current combined with high starting torque is required, however, a modified form of rotor winding may be used to satisfy the imposed starting limitations.

Where unusually high torque per ampere is required at starting, a double squirrel-cage winding is used, in which the outer winding has high resistance and low reactance and the inner winding has low resistance and high reactance; see Fig. 6. The former is effective during starting, giving a high starting torque and the latter becomes effective under running conditions, giving low slip and good full-load efficiency. The division of rotor currents between the two cages is accomplished automatically; at starting, the current is rejected by the inner winding, due to high reactance of the embedded bars while subjected to line frequency; when running, the current flows in the inner winding, since the rotor reactance is negligible at slip frequency and the resistance of the windings is the predominating influence on the division of rotor current. With the increased rotor reactance, such a motor must necessarily sacrifice power factor and maximum torque. In fact, the reactance is not only greater than that of the standard motor because of the two cage windings, but because of the magnetic bridge placed between the

windings to increase the selective current action between the windings when starting.

For full-voltage starting where there is required a value of starting torque per ampere intermediate between that furnished by the standard and the double squirrel-cage constructions, a "deep-bar" rotor may be used. The thin, deep rotor bars favor the occurrence of eddy-current losses when starting, thus increasing the effective resistance and the torque. When running at slip frequency, the resistance returns to normal value, with good full-load efficiency. The power factor and maximum torque are somewhat lower than those of the standard motor. This type of construction does not offer such difficulty in design nor in construction as does the double squirrel-cage type; the cost is less, and where full-voltage starting is desirable, the "deep-bar" motor may often be applied where standard squirrel-cage motors are not entirely suitable.

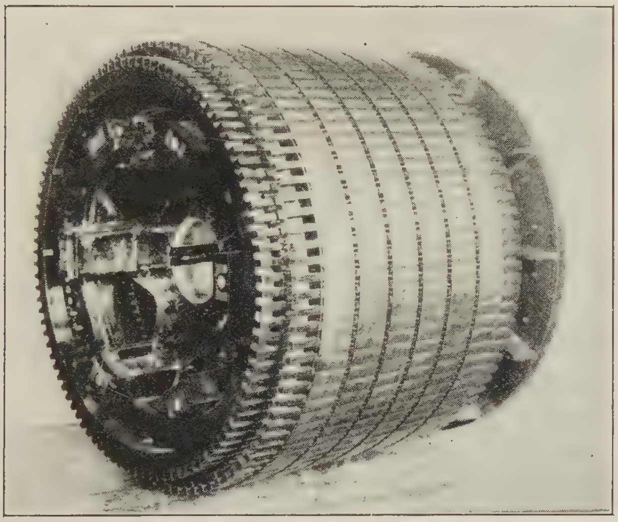

Fig. 6—Double Squirrel-Cage Rotor
One blower removed

## Collectors and Brush Rigging

Alloy collector rings for large induction motors have never been a great source of trouble nor have they been greatly changed. In recent years, the process of manufacture has been modified, and "chilled molds" have been used; the material becomes of more uniform structure, while the finer grain at the ring surface results in better ring wear. A microscopic analysis of rings made by this process shows that the metal is very uniform in composition and that the arrangement of the grain of the material is all radial to the surface.

To prevent trouble between neighboring brush shunts, and to increase insulation creepage distances for motors used in plugging service, the distance between rings has been increased.

The insulation on bushing type collectors has been improved considerably. The sleeve between rings and collector bushing is made of mica, built up on the bushing. Mica is more durable than other materials and is not damaged by the heat from the rings when these are shrunk on. Mica and the cement with which it is treated form a good arc-resisting surface.

The dust from the brushes is of high conductivity and must not be allowed to form a coating on the surfaces between the rings. To facilitate cleaning the collector while the motor is running and to protect the connecting studs and bushing from oil and foreign material, insulating sleeves are placed below the ring surface between adjacent rings. The entire collector is treated with arc-resisting cement to seal all small openings; a final coat of varnish gives a smooth surface which will not hold dust. The method of attaching the connection studs to the rings on bushing type collectors has been improved. The original method used was simply to tap out the rings to a rather coarse thread, screw in the studs, and complete the fit by running in solder around the joints. Vibration occasionally caused a loosening at this point. To remedy the trouble, a fine thread is now used, insuring a tightly fitted stud.

Increased output from a frame of given mechanical dimensions made necessary the collection of increased secondary currents. The most simple solution was to change from a carbon or graphite brush to a metallized graphite brush, making possible an increase of some 50 per cent in the brush current density, without an increase in temperature. Although the metallized graphite brush is not recommended for all applications, this type is well suited for average large induction motor service, where a greater range of characteristics is permissible than for other types of machines requiring current collection.

## Bearings

Attention to ventilation and electrical design has yielded increased torques for a given rotor weight. This has made possible a reduction in ratio of bearing length to diameter for a motor of a given torque, in those cases where the torsional stress in the shaft was. the limiting feature in choosing the proper bearing sizet This resulted in reduced weight and better alinemen- of the bearings. For very high speed motors, the bearing surface velocities might be too high for such a change. For general applications of moderate and slow speed motors such as in steel mills or hoisting service, however, a new style of pedestal bearing was adopted, having a length-to-diameter ratio of 2. Formerly, bearings had ratios of 2½ or greater. The new pedestals have a very small height to the bearing centerline, and other proportions give a sturdy design to successfully withstand shocks and vibrations from the driven apparatus.

*Improvements in Bearing Babbitts and in Methods of Pouring.* At one time, no great amount of attention was paid to bearing metals or to their application. Increasing demands on the bearings soon indicated the necessity for more scientific babbitt composition and

methods of pouring. The thorough cleaning of anchor holes in the bearing shells, their proper location, and a number of minor changes proved of some benefit. The substantial improvements, however, have been made in recent years. Frequent analysis of the babbitt metal in the melting pots and daily Brinell tests secure uniformity; the use of new metal only has maintained the purity of the alloys.

The pouring of babbitt at the proper temperature, which is very essential, is assured by the automatic temperature control of the electric melting pots. The use of self-skimming ladles and the thorough stirring of the molten babbitt have proved beneficial. The installation of electric ovens has promoted a uniform heating of the shells, thus securing the maximum advantages of preheating. In addition, the training of workmen and the control of all babbitt work by a skilled supervisor have greatly improved the consistency of the product.

*Bearing Lubrication; Oil Leakage.* Continual improvements of a general nature have been made in the construction of the sleeve type of bearings, to exclude dirt and dust from the bearing and to overcome oil throwing, objectionable features in the older designs. For those motors which must operate in a location exposed to dust or foreign material which might damage the bearings, special washers are fitted tightly about the shaft and holes leading to the bearing housing are equipped with bolted-on covers or with screw-plugs. These measures effectively make the bearing housing "dust-proof."

For high-speed motors, where the rotor blowers create considerable pressure drop at the inside end of the bearing housing, it is necessary to install a pressure-equalizing duct to prevent oil leakage. This consists of a pipe or duct arrangement covering the space around the shaft on the inner end of the housing and connecting to the air space outside the motor, which is at normal pressure. In the case of bracket-type motors, the duct takes the form of a pocket or channel cast in the bracket, but for large pedestal-type bearings it may consist of an external sheet or casting bolted around the pedestal.

## Manufacturing Improvements

*Balancing.* Since larger electrical machines have been built at increased speeds each successive year, the subject of vibration and methods for eliminating vibration have received an increasing attention. The troubles resulting from vibration are well known for any class of machine; in the induction motor, there result hammered bearings, weakened insulation or supports, loosened bolts, and a general deterioration.

For several years, large induction motors which operate at high speeds have been dynamically balanced to prevent excessive vibration; the minimum operating speed for motors requiring such balance depends upon the rotor weight. Former methods of balancing usually consisted of a static balance alone, which might only partially prevent vibration of the motor when running. Formerly, balancing was more or less of a "cut-and-try" method, whereas the recent method of dynamic balancing reduces the problem to a definite basis; the solution may be reached quickly and accurately.

The general method it to support the rotor and shaft on a cradle which is pivoted at one end, and free to move on the other end in one plane only against the resistance of a resilient spring system. The springs are so chosen that the critical period of vibration corresponds to a speed below that at which the motor will normally operate. The rotor speed is then adjusted to the resonant speed of the spring system; the increased amplitude of vibration at this speed facilitates adjustment of a counter-balancing system. This counter-balancing system consists of rotating weights, which form a couple, adjustable both in magnitude of the moments with respect to the fulcrum and in anguler position with respect to the rotating parts being balanced. Calibrated adjustments indicate the proper masses to be attached to the rotor, and their positions to give dynamic balance. Balancing is carried out for both ends of the rotor.

*Dipping and Baking Facilities.* The advantages of dipping and baking complete stators and rotors have been mentioned in a previous portion of this paper. The process has proved so practical that shop facilities for dipping and baking have been greatly increased in recent years. Arrangements for dipping or "flowing-on" of the varnish are made in convenient proximity to suitable draining tables and drying ovens. The change from steam to electric heat for these ovens has made convenient the use of automatic heat control.

The proper air circulation in the ovens is important and is maintained by motor driven blowers, and graphic meters are used as a record of the baking temperatures. The installation of various filters keeps the varnish perfectly clean before application to the motor parts. Research is continually carried on to determine the most effective methods and limits for the dipping and baking processes.

## Performance

The operating performances of large induction motors can hardly be mentioned as an improvement, unless the great reduction in motor weight per horse power is also considered. Using less and less active material in the motors, and with increasing iron inductions, it has been necessary to use better grades of iron and smaller air-gaps to maintain the same performance.

The effect of the deep-bar and double squirrel-cage constructions upon motor performance has been discussed. The power factor is several per cent lower at full load than that of the standard motor, while the efficiency largely depends upon the starting torque

required. For very high starting torques, the full-load efficiency is lower than that of the standard motor.

### Motor Accessories

Space heaters have become a popular accessory for large induction motors, preventing the formation of moisture upon the insulation during motor shut-down. The temperature of the coils is maintained at 5 to 10 deg. cent. above the room temperature, the circulating air from the heaters serving to keep the coils at this temperature.

The heaters are energized from a low-voltage source, and for large motors may be interlocked with the main circuit breakers to prevent simultaneous operation of motor and heaters.

The insulation of a large induction motor, like that of any electrical machine, must be protected from excessive temperatures. Thermometers or indicating elements placed on the iron parts or on the coil-ends give no direct indication of the internal coil temperatures, especially where the imbedded coil length is great. To afford a more accurate indication of the temperature to which the insulation is being subjected, or to protect against motor failure due to sustained overloads, resistance coils or thermocouples are frequently employed within the motor, operating in conjunction with some indicating device or relay circuit.

The use of temperature detectors is well known in connection with turbo generators, and has been extended to large induction motors to afford improved manual or automatic protection for these motors.

### Conclusion

The fact that induction motors are sold in a number greater than that of all other types combined, attests to the utility and worth of this kind of motor. Reliability, simplicity, low first cost, and ease of control have enabled the various types of induction motor to outsell their rivals in the power field. Design improvements, based upon practical operating experience and careful research, assure the continued success of this most useful power servant.

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## MEASURING A BILLIONTH OF AN INCH

Equipment to measure changes in length of the order of a billionth of an inch has recently been devised by P. P. Cioffi of Bell Telephone Laboratories. Such a length but about one-tenth the distance between the atoms of most metals would be required to equal a piece of ordinary tissue paper in thickness.

The need for so refined an instrument arose from studies of magnetic materials. This whole subject is one of the greatest practical importance to the American Telephone and Telegraph Company, because magnetization plays an essential part in all forms of electrical communication. For years, it had been assumed that pure soft iron had the highest possible permeability. The discovery of permalloy by G. W. Elmen of Bell Telephone Laboratories thus called at once for an explanation.

The task of supplying this was undertaken by Dr. L. W. McKeehan, also of the Laboratories' technical staff. He felt the secret lay in the amount of expansion or contraction that a metal undergoes when it is magnetized. In magnetizing a metal a loss is ordinarily suffered which evidences itself as heat. This varies for different alloys and it was surmised that the loss was closely connected with the change in length. This it was determined to verify.

To carry on the investigation it became necessary to have a measuring instrument of greater delicacy than any in existence. The development of such an instrument by Mr. Cioffi naturally entailed a great many refinements. The equipment is designed to measure changes of length in a piece of wire about four inches long. As imperceptible temperature changes cause expansion greater than the changes in length to be measured, every precaution is taken to keep the temperature of the wire constant. It is surrounded by a vacuum cylinder like a thermos bottle with an opening at each end and in addition a special electrical compensating coil is used to maintain constant temperature. The entire equipment is mounted on a spring suspension so that building vibrations will not affect it.

This study of magnetic materials well illustrates the research method which not only raises its questions and answers them but develops the necessary equipment to wring from nature her secrets. By the discovery of permalloy, telephone research has made a notable contribution to scientific knowledge and by Mr. Cioffi's refined measuring device has verified a new theory of magnetism.

# Auxiliary Power at Richmond Station

## Auxiliary Power System and Tests on House Turbine Generator

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and

A. C. MONTEITH[2]
Associate, A. I. E. E.

***Synopsis.****—This paper describes the auxiliary power system of the Richmond Generating Station of the Philadelphia Electric Company, mentioning briefly some of the factors which influenced the design of the system and discusses the starting of large motors at full voltage from an auxiliary turbine generator.*

* * * * *

IT is the purpose of this paper to describe the auxiliary power system of the Richmond Generating Station of The Philadelphia Electric Company, mentioning briefly some of the factors which influenced the design of the system, and to discuss particularly a most important feature of this system; namely, the starting of large motors at full voltage from an auxiliary turbine generator. At the time this system was designed practically no data were available on this subject, and as there seems to be a general trend in power station design toward the use of auxiliary turbine generators or auxiliary generators direct-connected to main units, it is believed that a discussion of some of the factors involved and the results of tests made at Richmond Station after installation will be of value.

### I. Description of Auxiliary Power System

*General.* Richmond Station is located in the northeastern section of Philadelphia along the Delaware River, about five miles from the central part of the city.

At the present time, the capacity of the station is 120,000 kw., made up of two turbine generators, each rated 60,000 kw., 0.85 power factor, 13,800-14,400 volts, three-phase, 60 cycles, 1800 rev. per min. Ultimately the plant will have a rating of at least 720,000 kw., and will consist of three separate building sections, each housing four turbo generators of at least 60,000 kw. capacity.

The first building section, which was completely constructed in the initial development, comprises three main parts; namely, boiler room, turbine hall, and switch house, with the boiler room nearest the river. Ultimately the boiler room will house 24 boilers. Twelve boilers have been installed initially, each rated at 1570 h. p. and equipped with a superheater, an economizer, and an air preheater. Two induced-draft and one forced-draft fans are provided per boiler. Included in the turbine hall and its mezzanine galleries and basement are the main generating units (Fig. 1), condensers with their auxiliaries, heaters, evaporators, deaerators, boiler feed pumps, river and city water pumps, air compressors, auxiliary power generator and buses, generator and exciter field rheostats, main generator ventilating equipment, etc. In the switch house are installed duplicate 13,200-volt buses, oil circuit breakers, disconnecting switches, reactors, etc., all arranged for vertical phase isolation. A connecting building between the turbine hall and the switch house contains the d-c. power room, battery room, pipe room, and operating room. Transformers supplying all 2300-volt auxiliary power load and induction regulators for the three tie lines to Delaware Station are located outdoors between the turbine hall and the switch house.

Fig. 1—Main Generating Units

*Auxiliary Power Supply.* The auxiliary power system at Richmond Station is radically different from the systems at Delaware and Chester Stations, other major plants of the Philadelphia Electric system, due principally to differences in methods used for maintaining heat balance.

At Delaware and Chester, although electric drive is used extensively for auxiliaries, a number of the auxiliaries have steam drive; all boiler feed pumps are steam driven; one of the duplicate circulating water pumps provided for each unit has a dual drive by turbine and motor, the other circulating water pump

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being motor-driven and used only in emergencies; one of the two air pumps and one of the two condensate pumps of each unit are steam driven, the other air and condensate pumps being motor driven. Exhaust steam for feed water heating is obtained by running the proper number of steam-driven air and condensate pumps with the boiler feed pumps and dual drive circulating water pumps. Small adjustments to maintain the proper amount of exhaust steam are made automatically by varying the governor setting on the turbine of dual drive circulating water pumps. In view of the fact that steam drive is provided for those auxiliaries which are most essential to the continuous operation of these plants, a supply from the main buses of the station is entirely satisfactory for service to the electrically driven auxiliaries; consequently a layout wherein the entire alternating current auxiliary power supply is obtained from transformers connected to the main 13,200-volt buses was adopted for Delaware and Chester stations.

For Richmond station, investigations made subsequent to a study of many of the most modern plants in this country and abroad, indicated that for the conditions under which Richmond would operate, three-stage heating would be most economical. Accordingly, bleeding of the main turbines was adopted. Bleeder connections are provided at the tenth, twelfth, fifteenth, and eighteenth stages (the turbines are 20-stage, Curtis type). Tenth stage bleeder steam is used only to heat the building and to increase the capacity of evaporators in case of any excessive demands for make-up water. The three other stages are used in the normal operation of the heater system.

The adoption of stage bleeding for Richmond not only eliminated any need for steam driven auxiliaries as regularly operating units, but made such drive undesirable from the standpoint of operating economy. Electric drive was therefore a necessity for all auxiliaries except those installed for standby service only.

The requirement of electrically-driven auxiliaries carried with it the further requirement of a source of electrical power having the highest degree of reliability for service to motors driving the most essential auxiliaries, such as boiler feed pumps, circulating water pumps, air and condensate pumps, generator ventilating fans, etc. Consequently, a supply from the main buses of the station could not be used for these auxiliaries, since in case of bus trouble or severe system disturbances, this source might be so seriously affected as to cause the loss of these most important auxiliaries. However, a supply from the main buses was adopted for the less essential auxiliaries and for those auxiliaries, such as boiler fans, which it might be desirable to have shut down in case of a sudden loss of station load.

Three alternatives were considered in deciding on a source of power for the essential auxiliaries; namely, auxiliary turbine generators, auxiliary generators on main unit shafts, and transformers connected to main generator leads between the generator terminals and the main oil circuit breaker. Both first cost and operating cost of turbine generators eliminated them from consideration as regularly operating units, although an emergency non-condensing unit, suitable for starting large motors at full voltage as discussed elsewhere in this paper, is provided. Generators on the main unit shaft, although providing auxiliary power at low cost, added undesirable mechanical complications to the main unit, and as it was desired to have shaft-end exciters on the Richmond units because of their successful operation at other plants, this alternative was also eliminated from consideration. Accordingly, the use of transformers connected to main generator leads was adopted. This scheme has the advantages of high reliability, low first cost, and low operating cost, and although it introduces an electrical complication, the great reliability of modern transformers made this complication of but slight importance. The scheme is also open to the objection that should the unit be disconnected automatically while carrying a heavy load, either the overspeed device on the main turbine may operate causing the loss of auxiliaries, or, if the overspeed device does not operate, the auxiliary system will be subjected to a high overvoltage until the voltage regulator functions to bring the voltage back to normal. This objection can be overcome by careful adjustment of the overspeed device and by installing equipment designed to withstand the overvoltage. Equipment so designed has the advantage of high factor of safety under normal operating conditions.

As installed, the auxiliary power system at Richmond Station consists of five principal parts as follows:

1. A 2300-volt, three-phase, 60-cycle supply for boiler fan motors and large less essential auxiliaries.
2. A 2300-volt, three-phase, 60-cycle supply for essential auxiliaries.
3. A 230/115-volt, two-phase, 60-cycle supply for small auxiliaries, lighting, etc.
4. A 250-volt, direct-current supply for stoker motors, emergency excitation, etc.
5. A 250-volt, direct-current supply for control of oil circuit breakers, etc.

The 2300-volt supply for boiler fan motors and large less essential auxiliaries such as motor generator sets, fire and water pumps, is obtained from three (ultimately four) 3750-kv-a. oil-immersed, self-cooled transformer banks located between the switchhouse and turbine hall and supplied from the main 13,200-volt buses in the same manner as outgoing lines. These banks feed duplicate sectionalized 2300-volt buses located between turbine hall and the boiler room so that cable runs are of minimum length.

The 2300-volt supply for essential auxiliaries is laid out on the unit principle. A 2500-kv-a., oil-immersed, self-cooled transformer bank, also located outdoors between the switchhouse and turbine hall, is connected directly to the terminals of each generator and supplies a short bus installed on a gallery under the turbine hall

floor. All essential auxiliaries associated with the generating unit are connected to this bus. To supply these auxiliaries while starting the unit, and also to act as reserve sources, each of these unit auxiliary buses is provided with two ties, one to the general 2300-volt system and one to another 2300-volt bus to which the auxiliary turbine generator may be connected. Thus each unit auxiliary bus has three separate sources of power. The breakers controlling these sources are interlocked so that normally no two of them can be paralleled, although provision is made to alter the interlocking by a synchronizing plug in case it is desired to parallel the auxiliary generator with the general 2300-volt system. In starting up a generator, the unit bus is usually supplied from the general 2300 volt system, and after the machine has been synchronized and connected to the station bus, the unit bus is connected to the transformer bank on the generator terminals. Suitable relays give an audible alarm in event of failure of voltage on the unit bus.

The 230/115-volt, two-phase supply is obtained from two (ultimately three) 1000-kv-a., oil-immersed, self-cooled, Scott-connected transformer banks supplied from the general 2300-volt system and located outdoors under the 230-volt power room at one end of the turbine hall. Adjacent to the 230-volt power room is an emergency valve control room from which all main electrically-operated valves can be closed.

The 250-volt direct-current system provided for the supply of stoker motors, emergency excitation, emergency lighting (automatic on failure of the alternating current supply), miscellaneous power, etc., is fed by three 200-kw. motor-generator sets and a 156 cell storage battery. The other 250-volt direct-current system supplies power for operating oil circuit breakers, valve motors, indicating lamps, etc., and is fed by two 20-kw. motor-generator sets and two 120 cell storage batteries. This system is entirely separate from the stoker and emergency excitation system, although an emergency tie is provided between the two. Control circuits of main and selector oil circuit breakers are operated on separate parts of the control system.

A diagram of the auxiliary power system at Richmond is shown in Fig. 2, which also indicates a typical normal method of operation. It will be noted that the system is so sectionalized that failure of any transformer bank, bus section, etc., will result in interruption to a minimum number of auxiliaries, and that such auxiliaries as may be affected can be either switched quickly to another source or replaced by duplicate units.

A list of the steam driven auxiliaries is also included in Fig. 2. All of these auxiliaries are intended for stand-by service only.

*Motors.* Table I lists the major auxiliary motors at Richmond, with their rating, type, method of starting, method of speed control, etc.

In general, all alternating-current motors above approximately 50 h. p. are supplied at 2200 volts, three-phase, while those below are operated from the 220-volt, two-phase system. However, for special

TABLE I
MAJOR AUXILIARY MOTORS
RICHMOND STATION

| Auxiliary | Motor rating | Type of motor | Starting | Speed control | Automatic restarting |
|---|---|---|---|---|---|
| Boiler feed pumps | 550 h. p. | Wound-rotor | Secondary resistance Push button | 10 per cent range 18 points automatic | Yes |
| Circulating pumps | 500 h. p. | Squirrel-cage | Full voltage— Push button | .... | Yes |
| Air pumps | 50 h. p. | Squirrel-cage | Full voltage— Push button | .... | Yes |
| Condensate pumps | 100 h. p. | Squirrel-cage | Full voltage— Push button | .... | Yes |
| Generator ventilating fans | 150 h. p. | Squirrel-cage | Full voltage— Push button | .... | Yes |
| Forced draft fans | 125 h. p. | Wound-rotor | Secondary resistance Controller | 50 per cent range 5 points | Yes |
| Induced draft fans | 60 h. p. | Wound-rotor | Secondary resistance Controller | 50 per cent range 5 points | Yes |
| Stokers | 15 h. p. | D-c. shunt | Resistance— Controller | 80 per cent range 22 points | No |
| Fire pump | 200 h. p. | Squirrel-cage | Compensator | .... | No |
| River water pumps | 275 h. p. | Squirrel-cage | Full voltage automatic from float switch | .... | Yes |
| Air compressors | 190 h. p. | Synchronous | Full voltage— Push button | .... | No |
| Stoker supply motor generator sets | 290 h. p. | Synchronous | Full voltage— Push button | .... | No |

services such as those required for cranes or in the screen house, motors as large as 80 h. p. are supplied at 220 volts.

In the design of the auxiliary power system, careful investigations were made as to the proper types of motors to be installed for the various auxiliaries. In the case of boiler fans, several types were considered including brush shifting a-c. motors, d-c. motors with variable field and armature control, as well as the standard wound-rotor motor which was finally adopted. For stoker service, both a-c. and d-c. motors of various types were considered before a decision was reached to install the variable-speed d-c. shunt motor.

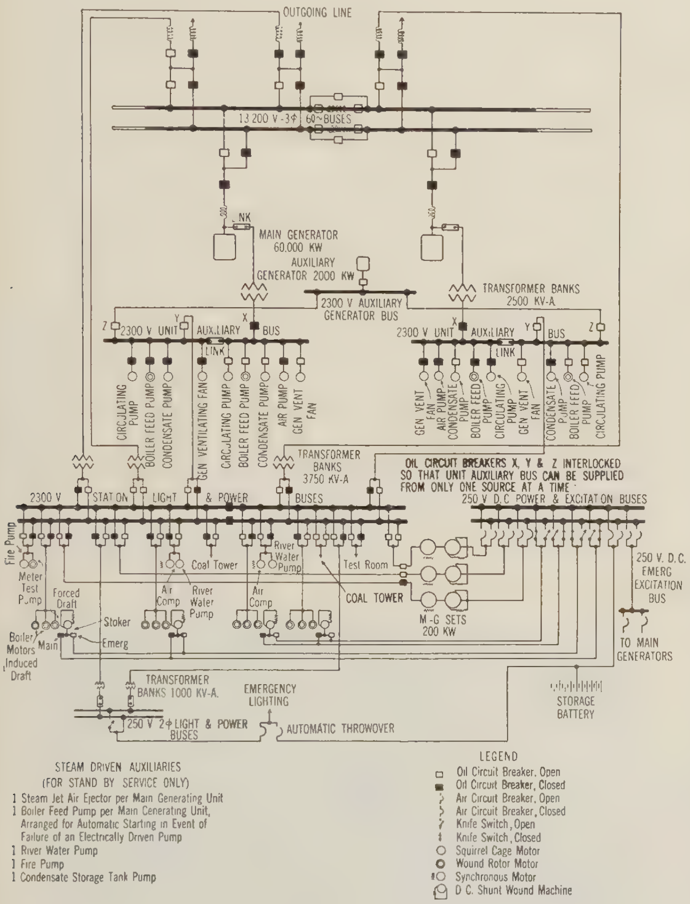


FIG. 2—STATION AUXILIARY SYSTEMS AND TYPICAL NORMAL METHOD OF OPERATION

*Motor Controls.* Boiler feed pump motors are started and stopped from push button stations near them. In starting, a block of resistance is inserted in the rotor circuit and is short-circuited automatically when the motor is up to speed. Speed control may be obtained either manually from a push button station or automatically from a pressure regulator set to maintain the proper differential between feed water and steam pressures. A pilot motor controlled by the push button station or by the pressure regulator operates a drum controller which varies the amount of resistance in the rotor circuit of the motor. In case of loss of voltage, the starting resistance is automatically connected in the circuit, and upon restoration of voltage, the motor again comes up to the proper operating point.

Wound-rotor motors driving draft fans are controlled from manually operated controllers located at the boiler control panels. Control equipment is so arranged that the controller may be set at the desired operating point, and the motors will come up to this speed without additional manipulation of the controller. In event of loss of voltage, contactors operate to connect all resistance in the rotor circuit, and when voltage is restored, the motor comes back to the operating point for which the controller is set.

In connection with the control of constant speed motors, careful consideration was given to the various methods of starting that were applicable; namely, compensator starting, reactor starting, and starting at full voltage.

When the older stations were placed in service compensator starting was used extensively. However, as is well known, this type of starting has several serious objections, when used in large power stations, the outstanding one of which is the danger to life that may result from failure of the compensator. Other less important objections are the fact that the motor is subjected to two heavy current inrushes, one at the time of starting and one at the time of throw-over from partial to full voltage, and the fact that automatic control with compensators is relatively complicated. As a result, reactors with shunt oil circuit breakers rather than compensators were used in several new installations, and on a number of existing installations, compensator starting was replaced by reactor starting. However, although reactor starting greatly lessens danger to life, results in only one shock of current inrush to the motor, and is easily adapted to automatic control, it has the disadvantages of relatively high cost and large space requirements. In considering the type of starting to be used at Richmond Station, all of these features of compensator and reactor starting were taken into account and compared with starting at full voltage, with the result that full-voltage starting was adopted for all of the most important constant-speed auxiliaries except the fire pump, which had to be installed for construction purposes prior to the final design of the auxiliary system. Full-voltage starting not only eliminates the explosion hazard, but results in installations of minimum cost and control systems of the utmost simplicity wherein automatic restarting after an interruption is easily obtained. This last feature is particularly important, since the station operators can concentrate their attention elsewhere at times of trouble. This type of starting has, of course, the disadvantages of high current inrush during starting, possible damage to the motor because of the heavy mechanical forces to which the windings are subjected and possible damage to the driven equipment because of the high starting torque developed. However, with the usual large amount of generating capacity in

operation, the voltage dip resulting from the current inrush is negligible, and by proper mechanical design, the possibility of damage to the motor or to the driven equipment is very remote.

As installed, the synchronous motors at Richmond are controlled from push button stations. Pressing the starting button closes an oil-immersed contactor which connects the motor to the line. The field contactor closes automatically at the proper time. Protective equipment includes relays which open the field circuit

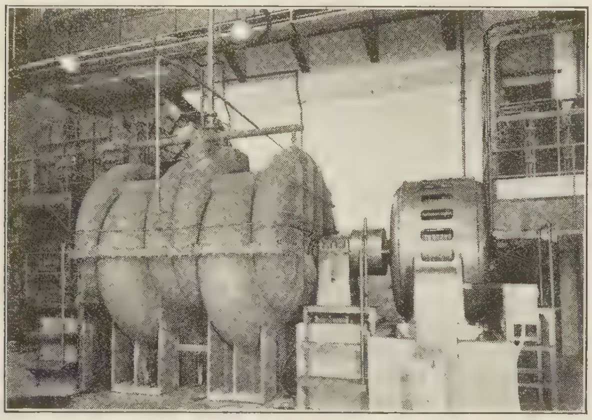

Fig. 3—Circulating Pump and Motor

in event of loss of a-c. voltage and which disconnect the motor from the line in case of loss of field, and also a time-delay low-voltage relay which on failure of a-c. voltage opens the oil-immersed contactor but which in case of short circuit in the armature winding, permits the clearing of the line oil circuit breaker before the contactor opens.

Control equipment for squirrel-cage motors consists merely of an oil circuit breaker in the motor leads controlled from a twin pull button switch of the usual type located near the motor.

As shown in Table I, the largest constant speed motors started at full voltage are those driving circulating water pumps. These motors (Fig. 3) are rated at 500 h. p., 2200 volts, three-phase, 60 cycles, 225 rev. per min. Full-load current is approximately 140 amperes, and starting current is around five times this value. Although these motors can be easily started under normal conditions, when they are supplied either from the main station busses or directly from the main generating units, the question of starting them from the auxiliary turbine generator was a problem of paramount importance, and was given very careful study both by the engineers of the Philadelphia Electric Company and by those of the Westinghouse Electric and Manufacturing Company, which furnished the auxiliary turbine generator.

As the auxiliary unit was for stand-by service only, it was desired, of course, to provide as small a unit as possible in order to keep investment costs at a minimum. However, in event of a complete interruption to the station, the unit must be able to start and carry sufficient auxiliaries to permit resumption of service. Since the circulating water pumps were the largest auxiliaries to be considered, the ability to start three such pumps in succession with valves closed was fixed as the duty to be met by the auxiliary unit. As a result of the study of this question, a unit of special design with a standard vibrating type voltage regulator was installed. The unit is rated 2000 kw., 3333 kv-a., 0.6 power factor, 2300 volts, three-phase, 60 cycles, 3600 rev. per min. (Fig. 4) and can be brought up to speed ready for load in fifteen seconds. Starting is accomplished by operating a motor-driven bearing oil pump; when the bearing oil has reached the proper pressure, a contact-making pressure gage opens an electrically-operated valve in the steam line to the turbine.

## II. Full Voltage Starting of Large Motors

*General.* On account of the greater simplicity and reliability of the control equipment, and the ease with which automatic restarting can be obtained, the decided tendency has been towards the use of full-voltage starting on as many of the auxiliary motors as possible. A careful study of the problem of properly insulating motors for this class of service has been made, and the results of this study have been presented to the Institute.[3] As a result of these and subsequent tests, there seems to be no question that all squirrel-cage induction motor windings can be braced to withstand the mechanical effect due to full-voltage starting. A

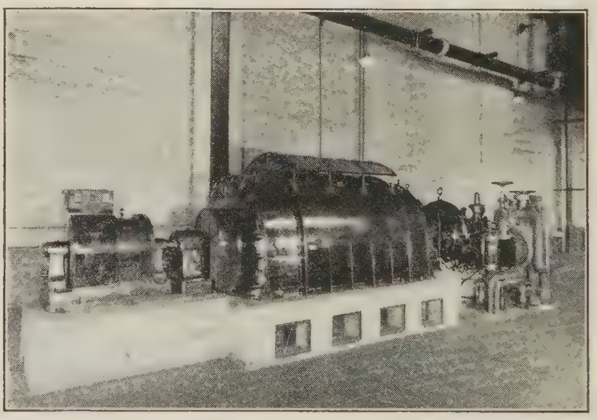

Fig. 4—Auxiliary Turbine Generator

large number of the motors designed for low-voltage starting can be used when full-voltage starting is desired. The large high-speed motors, which have comparatively high starting currents and long coil extensions, require some additional bracing.

In power stations, where the motors are started on the main auxiliary bus fed from the main unit, the

3. J. L. Rylander, *Effect of Full Voltage Starting on the Windings of Squirrel-Cage Induction Motors*, A. I. E. E. Trans., Vol. 44, 1925, p. 53.

starting of the motors on full voltage is usually a matter of mechanical considerations of the load. The drop in voltage at the motor terminals is due to the leakage reactive drop of the transformers and the drop in the cable and bus connecting the motor to the transformers. This is small as the transformer capacity is much greater than the largest motor to be started.

When the auxiliaries are started from a small auxiliary unit not only the voltage drop due to the reactance of the generator and the drop in the leads, but also the effect of armature reaction must be considered. This may appear serious, when it is desired to start large motors, but there are several inherent properties in this particular application which make it possible to start such motors, provided good voltage regulation is not essential during the starting period.

*Effect of Generator Characteristics.* If calculations of the voltage drop are made assuming that both the generator reactance and armature reaction become effective instantly, and that the impedance of the load remains constant, a low value of voltage is arrived at. These are probably questionable assumptions but they are commonly used in making calculations. Since it takes time for the armature reaction to become fully effective, and also the effective motor impedance increases with speed, smaller voltage drops are actually obtained on test. When a three-phase short circuit is placed on a generator of this type, the flux will have reached a constant value in about 1.5 seconds. This is an average value for several machines. Increasing the external reactance considerably increases the time for the flux to become constant.

Low internal reactance is desirable as it reduces the instantaneous drop in voltage when a load is applied to the generator. Low reactance is inherent in the comparatively low-capacity high-speed turbine generators used for auxiliary units.

When hand regulation is used, high short-circuit ratio or good inherent voltage regulation is desirable, as the starting currents of squirrel-cage induction motors are of low power factor. This can be obtained either by using a generator of special design or a larger generator than necessary for the load or a combination of the two.

*Voltage Regulation.* A voltage regulator is essential when severe duty is placed on the auxiliary unit. It will not only keep the voltage constant on the auxiliary bus during normal operation but will maintain better voltage conditions when a motor is being started. High short-circuit ratio is not as essential when a voltage regulator is used. With the voltage regulator in operation the speed of response of the exciter has a decided bearing on the voltage drop obtained when a large motor is started. The higher the speed of response the nearer the effect of armature reaction is eliminated. A high speed of response is inherent in small high-speed exciters.

*Effect of Load Characteristics.* The characteristics of the load have a decided bearing on the size of motors that can be started with a given voltage drop. The motors driven from the auxiliary generator are usually the condensate, circulating water and boiler feed water pumps. All of these have torque characteristics which vary with speed. The torque on the circulating water pump motor varies approximately as the square of the speed. The others are nearly up to speed before the pump takes on load. The condensate pump motor is comparatively small, while the boiler feed pump is usually driven by a wound-rotor motor. The circulating water pump motor is in most cases the largest to be considered. At zero speed, the torque is only that necessary to overcome the static friction of the bearings. This allows considerable torque for acceleration, so that the motor will come up to speed very quickly and the low power factor starting current will decrease to normal full-load current of comparatively high power factor before the armature reaction has become fully effective. The voltage drop will, therefore, be less than if it took longer for the motor to reach full speed.

From the above it is seen that, if all factors are considered, it is difficult to calculate the voltage drop with any degree of accuracy. When Richmond station was being designed, calculations, using a step-by-step method, were made for several combinations of starting the circulating water pump motors. When the equipment was installed, tests which were made to determine the voltage drop, indicated better voltage conditions than calculated because pessimistic assumptions were used.

*Tests at Richmond Station.* The following is a brief description of the generator and the circulating water pump motors installed in the Richmond Station and the tests run.

The auxiliary generator is rated at 3333 kv-a., 0.6 power factor, three-phase, 60-cycle, 2300 volts at 3600 rev. per min. The leakage reactance is 5.6 per cent and the short-circuit ratio is about 1.7. No-load field current for 2300 volts is 68 amperes. The direct-connected self-excited exciter is rated at 33 kw., 250 volts and is a four-pole unit.

The 32-pole motors driving the circulating water pumps are rated at 500 h. p., three-phase, 60 cycles and 2200 volts. These motors have a starting torque equal to full-load torque, and a pull-out torque of 2.8 times full-load torque. The slip at full load is 3.3 per cent of synchronous speed. The pump has a calculated torque characteristic which varies approximately as the square of the speed down to 70 rev. per min. Below 50 rev. per min. the torque increases with decrease of speed. The calculated torque with the valve closed is 65 per cent of full-load torque at full speed.

Since the auxiliary generator was required to start three circulating pumps in succession and only two were available for the test, an equivalent load, consisting of two generator ventilating fans driven by 150-h. p., squirrel-cage motors and two boiler draft fans driven by 125-h. p. wound-rotor motors, was used. The two

pumps used were duplicate units on one condenser. In making the tests the generator and the above mentioned motors were isolated from the remainder of the station, so that complete tests could be made without affecting the operation of the station. Two six-element oscillographs with eight-foot films were used in obtaining records of the tests. Besides taking records of the auxiliary generator and exciter voltages and currents, one oscillograph element was connected to a special magneto, giving an indication of the speed of one pump at all times. The tests fall in four distinct groups.

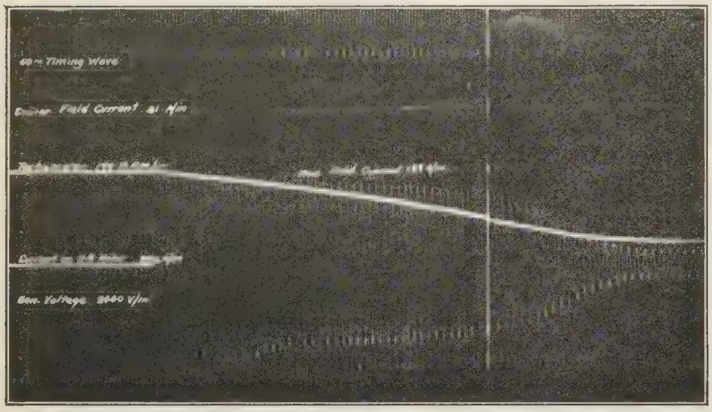

Fig. 5—Starting One Motor with Fixed Generator Excitation

*Group I.* One circulating water pump motor was started with no-load excitation on the auxiliary generator. With the pump valve in the open and closed position tests were made with the generator under control of the vibrating type of regulator and also with fixed excitation.

*Group II.* With the equivalent of one motor running and with the voltage adjusted to normal, a second motor was started with the generator under the control of the automatic voltage regulator and also with fixed excitation. The pump valves were open for these and subsequent tests.

*Group III.* With the equivalent of two motors running, and with the voltage adjusted to normal, a third motor was started with the generator under the control of the automatic voltage regulator and also with fixed excitation.

*Group IV.* With no-load excitation on the generator, the two ventilating fans, the two boiler draft fans and one circulating pump motor were started together, and, after an interval, a second circulating pump motor was started. These tests were made with the generator under control of the automatic voltage regulator and with fixed excitation.

Several other miscellaneous tests which were made will be referred to when the results of the above tests are reviewed.

*Tests Results.* Sections of two of the oscillograms taken are shown. Fig. 5 shows the starting of a motor with fixed excitation on the generator. Fig.6 shows the starting of a motor with the generator under control of the automatic voltage regulator. Oscillograms taken simultaneously with those shown give the generator currents, exciter terminal voltage and a timing wave. For the oscillograms shown the generator and motor currents were the same. In order to make the test results easier to interpret, the various values have been scaled off the oscillograms and plotted. The curves with broken lines indicate the results when the automatic voltage regulator was in operation, while those with solid lines indicate the results of the tests when fixed excitation was used on the generator. This same notation will be used throughout.

The results of the tests under Group I are shown in Fig. 7. With fixed excitation, the voltage dropped from 2350 volts to 1850 volts in about one second and the motor accelerated to 67 per cent of synchronous speed. From this point up to full-load speed the impedance of the motor increased rapidly, so that the current decreased. Assuming that the motor impedance is constant and that the effect of reactance and armature reaction becomes effective instantly, a value of 1400 volts is obtained with no-load excitation on the generator.

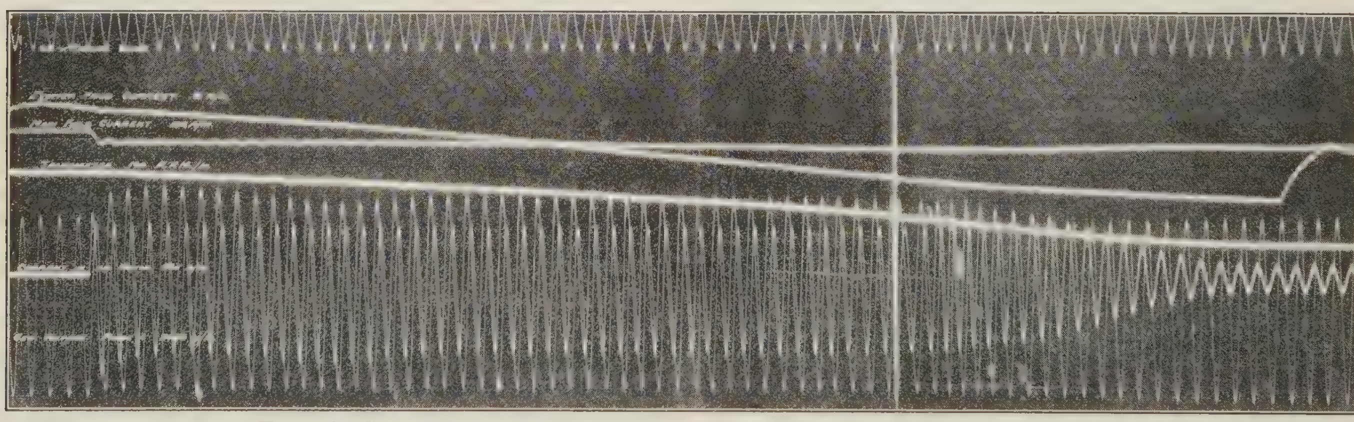

Fig. 6—Starting One Motor with Voltage Regulator in Operation

Whether the pump valves are open or closed makes very little difference on the time to accelerate the motor to full speed. For either condition the current decreased to approximately 110 amperes, gradually increasing to 140 amperes when the valve was open. The motor came up to full speed in both cases in 1.8 seconds with fixed excitation on the generator.

With the regulator in operation, a minimum of 2060 volts was reached in 0.4 seconds. The regulator became effective very quickly, bringing the voltage back to normal in 1.1 seconds. In this case it took 1.4

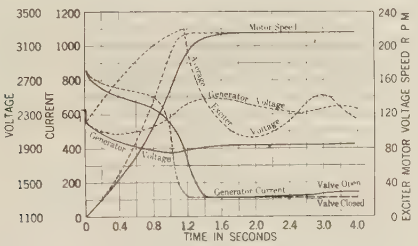


Fig. 7

seconds for the motor to come up to speed. The voltage was, therefore, normal before the motor reached full speed. The exciter terminal voltage built up from 110 to 220 volts in 1.1 seconds.

The results of the tests under Group II are shown in Fig. 8. Without the voltage regulator in operation, the voltage dropped to 1920 volts in one second, and the motor reached full speed in 1.6 seconds. With the regulator in operation, the voltage dropped to 2080 volts in 0.4 seconds, and the motor was up to full speed in 1.4 seconds.

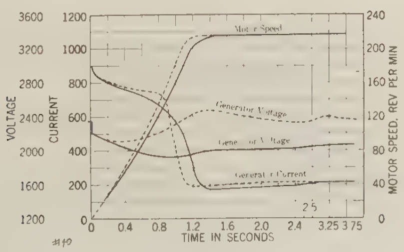


Fig. 8

The results of the tests under Group III are shown in Fig. 9. Without the voltage regulator in operation, the voltage was adjusted to 2540 volts on the generator with one motor running. The voltage dropped from 2540 to 2140 volts when the second motor was started, recovered to 2350 volts, and finally reached a minimum of 1600 volts when the third motor was started.

A record of the speed of the second motor was taken when the third motor was started. Although the voltage dropped considerably, the speed dropped gradually from 216 to 204 rev. per min. This drop in speed counteracted the voltage drop, so that the current taken by the motor only increased from 140 to 160 amperes. The inertia of the load already on the generator undoubtedly helped the conditions when the third motor was started. The tests show that the current taken by a motor actually decreases for a time. The effect of the inertia may be judged from two tests run. With the valve open and the condenser full of water, a test was made to see how long it would take the motor to stop. In four seconds the motor reversed, and at the end of nine seconds the motor had reached a maximum speed of 160 rev. per min. in this

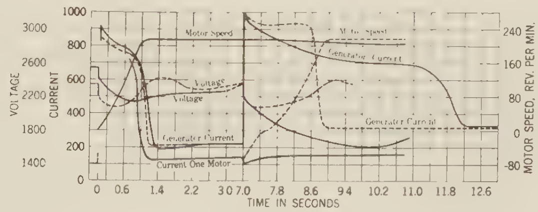


Fig. 9

direction, due to the water flowing out of the condenser. With the valve closed, it took about 40 seconds for the pump to stop.

With the voltage regulator in operation, the voltage dropped to 2080 when the second motor was started. The voltage had been restored to 2350 volts at the time of starting the third motor and dropped to 2070 in 0.4 seconds but was restored to normal in 1.7 seconds. In this case it took longer to bring the motor up to speed because it was running at 75 rev. per min. in a reverse direction when the voltage was applied. It took 0.6 second to stop the motor and a total of two seconds for the motor to reach full speed.

The results of the tests under Group IV are shown in Fig. 10. Without the voltage regulator in operation

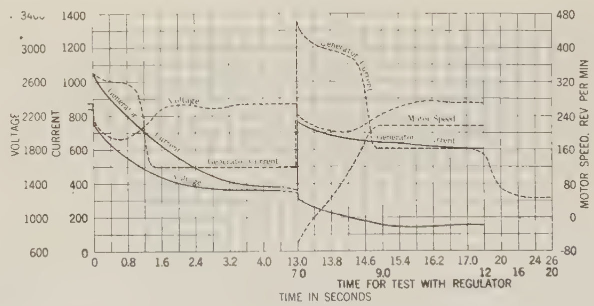


Fig. 10

the voltage dropped to 1300 volts in 13 seconds, and when the last circulating pump motor was started, the voltage dropped to 900 volts and remained there. The second pump was rotating in a reverse direction and the voltage was not high enough to produce sufficient torque to stop the pump before the test was discontinued.

Under regulator control the application of the first load caused the voltage to drop to 1920 volts in 0.6 second and it was restored to 2330 volts in two seconds.

When the second load was applied, the voltage dropped to 2000 volts in about one second and was restored to normal in 2.8 seconds. Again the pump was running at 70 rev. per min. in a reverse direction and it took a total of two seconds to start the motor.

The current, when the second load was applied, decreased rapidly to 600 amperes and remained at that value for a time, again falling to 315 amperes. The second drop no doubt indicates where some of the high inertia fans, started with the first load, approached full speed.

In no case did the average speed of the turbine fall more than 3 per cent. Although the currents were comparatively large the actual load was not excessive and came on gradually.

A test was made to determine the torque necessary to start the motor revolving. This was done by lowering the generator voltage and connecting the motor to the generator by closing the oil circuit breaker. It was found that with 750 volts on the generator, the motor revolved slowly. Considering that the starting torque varies as the square of the applied voltage, this indicates that it took approximately 11 per cent of full-load torque to start the motor revolving. This test was made after the motor had been run for a time.

It is seen from these tests that the actual voltage conditions are much better than calculated, such calculations being based on steady state conditions, assuming an instantaneous decrease of generator flux and constant motor impedance. The tests also show conclusively that an automatic voltage regulator has a decided stabilizing effect.

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Abridgment of

# Directional Ground Relay Protection of High-Tension Isolated Neutral Systems

BY J. V. BREISKY,[1] Associate, A. I. E. E.
J. R. NORTH[2] Associate, A. I. E. E.
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***Synopsis.***—*This paper discusses the problem of obtaining selective relay protection in case of accidental grounds on high-tension isolated neutral systems. A relay was developed whose overcurrent element operates on the residual charging current which exists when a ground occurs on such a system, and whose directional element is operated by residual charging current and residual voltage. Two schemes can be employed: One using high-tension potential transformers for energizing the voltage coil of the directional element; the other, which is more complicated but cheaper, making use of low-tension potential transformers.*

*Tests were undertaken on the 140-kv. system of the Consumers Power Co. to determine the effectiveness of this relay system under conditions of arcing and solid grounds. These tests were successful and it was therefore decided to make general use of such relay equipment for the high-voltage isolated neutral system. The relay scheme was put into operation during March, 1926, and the operating records available adequately substantiate the test results.*

* * * * *

## Introduction

SELECTIVE protection in case of accidental grounds on systems either solidly grounded or grounded through a resistance is a problem which has been solved for some time in a satisfactory manner. The paper which is being presented at this same convention by Mr. B. M. Jones and Mr. G. B. Dodds gives an outline covering the different relay systems which are commonly in use today. It was only for ungrounded systems, however, as well as systems grounded through an extremely high resistance, that no satisfactory solution had been found.

In this paper a relay protective scheme is described which offers a solution of this problem. It makes use of the residual charging current for timing and of the residual charging current and residual voltage for directional discrimination. It can be used successfully on underground systems operating at high voltages and having lines of considerable length.

## Theory and Design

*General Theory.* As is well known, the charging current obtaining on a three-phase system under normal conditions is caused by the capacity between wires as well as from each wire to ground. Since the capacity currents are equal in all three phases, the current in the neutral of three current transformers connected to the three phases of the system is normally zero. If a ground occurs on one of the phases, the balance is disturbed, however. While the charging current due to the capacity between wires is still the same, assuming that the ground current is not large enough to influence the potential between conductors considerably, the capacity from each wire to ground has changed. One of the phases is at ground potential, resulting in no charging current to ground, and the other two are now 1.73 times normal line to neutral voltage above ground. Therefore, a residual charging current results. This is shown schematically in Fig. 2, Fig. 2A giving normal conditions and Fig. 2B showing vector relations in case

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1. Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
2. Commonwealth Power Corp., Jackson, Mich.
3. Consumers Power Co., Jackson, Mich.

*Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 20-24, 1927. Complete copies upon request.*

of a ground on phase $A$; charging currents due to the capacity between wires are not given, as they stay balanced and do not contribute to the residual current. The vectors for residual voltage are also shown in Fig. 2. Under normal conditions, the secondary delta of the star-delta potential transformer is closed, giving zero residual voltage. The star side of the potential transformer must be grounded. In case of a ground on one of the phases, *e. g.*, phase $A$ close to the station, $E_a$

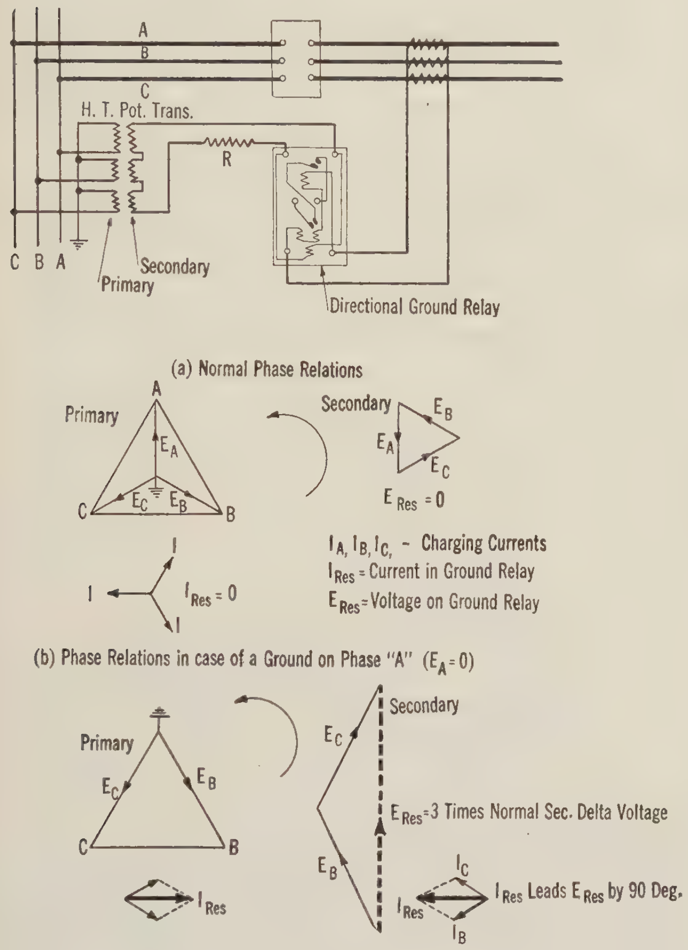


Fig. 2—Vector Relations on High- and Low-Voltage Side under Normal Conditions and in Case of Accidental Ground. Relay Scheme Employs High-Voltage Potential Transformers.

becomes zero, while $E_b$ and $E_c$ increase 1.73 times and also change in phase position. It is seen that the secondary delta is not closed any more and a residual voltage equal to three times the normal secondary delta voltage appears.

Studying the phase relations between currents and voltages, it will be noted that the normal charging current to ground in each phase leads the voltage between that phase and ground by 90 deg. and that under ground fault condition, the residual charging current also leads the residual voltage by 90 deg.

*Graphic Representation of Residual Charging Current.* In order to gain a clear conception of the operation of this relay system, the distribution of the residual charging current over the line must be studied. An excellent equivalent method of arriving at the residual currents has been published,[4] the gist of which is given here. With a solid ground at a certain point of the system, the potential between the grounded conductor and the ground is reduced to zero at that point, the normal potential between line and ground being indicated by $E_n$, Fig. 3. Instead of studying this problem now as a three-phase unbalance, let us assume that all constants of the system remain unchanged and that a single-phase potential whose value is $-E_n$ is superimposed over the normal potential at the point of accidental ground. The sum of these two potentials, $E_n$ and $-E_n$, is zero, corresponding to a solid ground. The only difference between the system under normal conditions and in case of an accidental ground is now caused by this superimposed potential $-E_n$. Due to the effect of this superimposed potential, a ground current $I_g$ is established which flows into the ground and divides itself up through the three parallel branches of the capacity to ground, $C$, of the polyphase system. It flows through these back to the ground connection, on the grounded phase directly and on the two ungrounded phases through the windings of the transformers; see Fig. 3B. In the grounded conductor, the ground current due to $-E_n$ neutralizes the normal

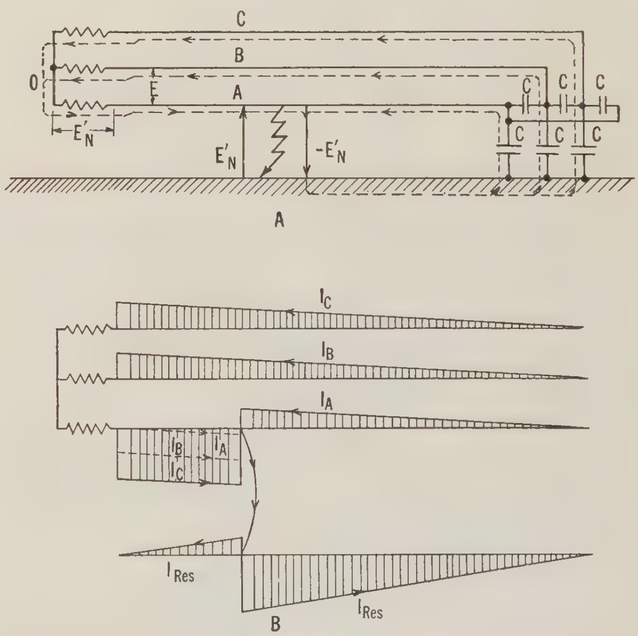


Fig. 3—Graphic Representation of Residual Charging Current

capacity current. The latter is not shown. In the ungrounded conductors, it adds to the normal capacity current.

The charging currents enter the system equally dis-

4. See R. Rüdenberg, "Electriscke Schaltvorgänge," pp. 150-152, Julius Springer, Berlin, 1923.

tributed over the entire length so that the current in all three conductors increases lineally from the far end. An interruption of the linear relation exists in the grounded conductor at the point of ground. To the right of the ground point, the current flows in the same direction as in the ungrounded conductors; to the left, that part of the ground current which is caused by the grounded line itself flows through its own circuit to the point of ground, increasing in the opposite direction. Also, the two currents of the ungrounded conductors combine and return over this conductor to the ground point.

The distribution of the ground or residual current is obtained by adding the charging currents in each phase. This current is also shown in Fig. 3B. In the earth, one part of the current spreads out along the conductor path to the right and the other to the left. Both have a linear increase.

This current distribution, due to the accidental ground connection, superimposes itself over the normal current of the system, both the normal capacity and normal load currents, and produces a single-phase load and therefore dissymmetry in the potential and current of the system.

The total residual charging current depends on the constants of the line and can be calculated rather accurately.

*Calculation of Residual Charging Current.* The capacity to ground is given by the formula:

$$C = \frac{0.03882}{\log_{10} \dfrac{2h}{r_0}} \ (\mu \text{ f. per mile})^5,$$

where

$h$ = height above ground in inches,

$r_0$ = equivalent radius of line conductors in inches.

The value of $r_0$ for different circuits may be computed as follows:

One circuit on pole:

$$r_0 = \sqrt[3]{r\,d^2}$$

Two circuits on same pole:

$$r_0 = \sqrt[6]{r\,d^5}$$

$r$ = average physical radius of conductor in inches,

$d$ = effective spacing of conductors in inches.

Capacity per mile, in farads:

$$C = \frac{0.03882}{\log_{10} \dfrac{2h}{r_0}} \times 10^{-6}$$

Admittance per mile, in mhos:

$$Y = 2\pi f C$$

The residual charging current in amperes per mile, in case of ground on one phase:

$$I = E_n Y \ (E_n = \text{line to neutral voltage})$$

5. Refer to Standard Handbook for Elec. Engrs., 5th edition, p. 82.

The series impedance, the impedance which the conductors offer to the flow of charging current, is negligible in comparison with the impedance to ground through capacity, and therefore has been neglected in the above calculations.

The residual charging current in a grounded polyphase system is three times as great as the normal capacity current to ground of each ungrounded conductor.

*Behavior of Residual Charging Current.* Referring back to the distribution of the residual charging current as shown in Fig. 3B, bottom, let us now note certain important facts in regard to the behavior of this current under different conditions of system connections and grounds.

a. The residual charging current is a maximum at the point of fault, and is zero at the far ends of the line.

b. The total value of residual charging current is practically constant for a given length of line, voltage, etc., no matter at which point of the line the ground occurs, neglecting the series impedance. This is illustrated in Fig. 4.

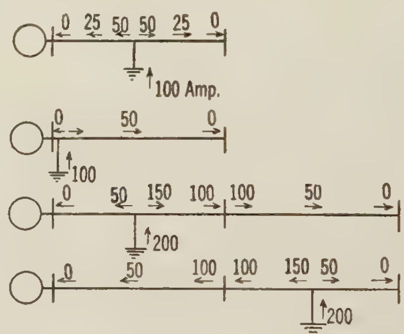


FIG. 4—DISTRIBUTION OF RESIDUAL CHARGE CURRENT

c. The value of the residual charging current is constant, regardless of the location of generating capacity, since no residual current can flow through ungrounded apparatus. The three line currents must add to zero in the apparatus.

d. In the case of single lines, the value of residual current at a given distance from the end of a line and for a given direction of current flow is constant no matter at which point of the system the ground fault occurs; also shown in Fig. 4.

*Relay Protection.* In order to utilize properly the characteristics of the residual charging current, a relay is used which has both a current and a directional element (see Fig. 2). The directional element utilizes the residual current and residual voltage and closes its contacts only if power flows in a given direction. The current element is energized by the residual current and can be used either on the definite minimum or inverse part of the time curve, since the relay can be set to close contacts in a given time with a certain current flowing. As mentioned before, the current through the relay is constant for a ground at any point

on the system, for a given system conenction and given direction of power flow.

Fig. 6 shows a typical radial single line system. The time settings of the relays for given currents are indicated, as well as the tripping direction of the directional element. Grounds are assumed at several points to illustrate the operation of the relay system.

Since there is no residual current at the extreme end of the line, charging current ground relays cannot be made to operate at that point. However, a residual voltage relay, as shown in Fig. 1, can be used at the far

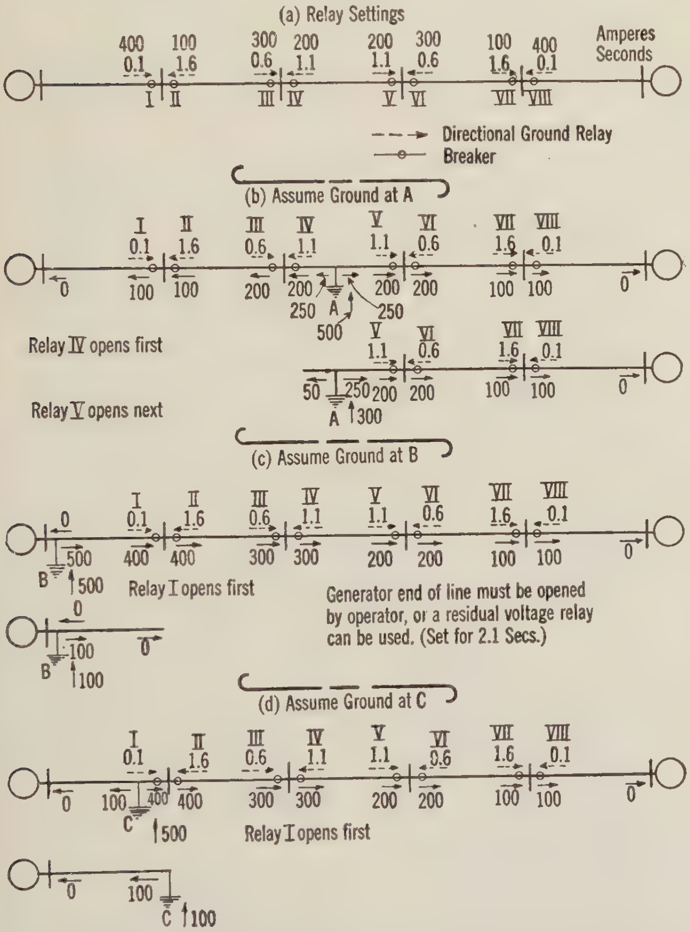


Fig. 6—Application of Directional Relay—Operating on Residual Charging Current—to a Radial Single Line System

end of the line, set for a long time delay so that it will not interfere with the time selectivity at other points.

*Protection of Parallel Lines.* The protection of parallel lines can be accomplished in two ways. The simplest solution is the use of differential current ground relays, operating on the unbalance of the residual currents in the parallel lines with a ground on one of them. Another solution is the use of directional current relays as employed on single lines, except that here they must be used on the inverse portion of the time curve to obtain proper selectivity.

This problem is discussed in more detail in connection with the relay system used by the Consumers Power Company.

*Design of Relay.* The design of this relay was a simple problem after the behavior of the residual charging current and voltage had been studied. A

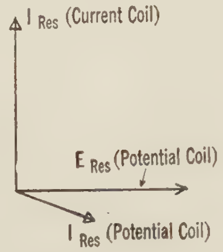


Fig. 7—Vector Relation of Current and Potential of Relay Coils

standard low energy directional relay is used, except for the current phase-angle relations in the potential coil. As is evident from Fig. 2, the residual charge-

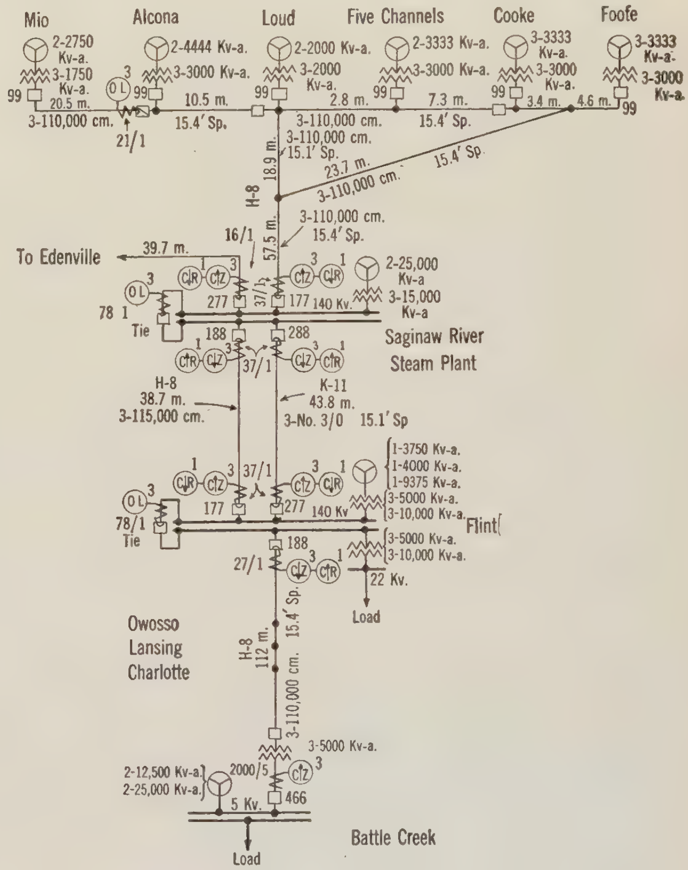


Fig. 9—System Connections of 140-Kv., 60-Cycle, H-8 System

current leads the residual voltage by 90 deg., neglecting a shift due to the series impedance of the line, which may shift the current 10 deg. to 15 deg.

The standard directional relay as used for short-circuit protection is designed to give maximum torque if the current in the current coil and the voltage in the

voltage coil are in phase. This is achieved by lagging the current in the potential coil by almost 90 deg., since maximum torque in an induction element is obtained with the two fluxes, or two currents, 90 deg. out of phase.

Now, in the residual charging current relay, the current normally leads the residual voltage by almost 90 deg. Therefore, to obtain good torque conditions,

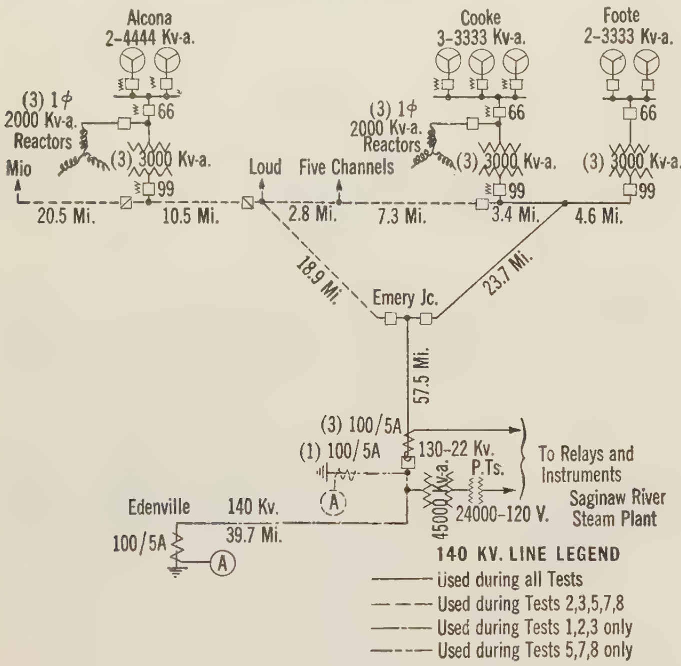


Fig. 10—System Connections used for Ground Tests—August 16, 1925

| Test No. | Line length | | Generating capacity | | |
|---|---|---|---|---|---|
| | Total | *Eff. | Station | Generators | Reactors |
| 1 | 128.9 | 89.2 | Cooke | 3-3333 kv-a. | 6000 kv-a. |
| | | | Foote | 2-3333 kv-a. | .. |
| 2, 3 | 188.9 | 149.2 | Cooke | 3-3333 kv-a. | 6000 kv-a. |
| | | | Foote | 2-3333 kv-a. | .. |
| | | | Alcona | 2-4444 kv-a. | 6000 kv-a. |
| 4, 5, 6 | 149.2 | 149.2 | Alcona | 2-4444 kv-a. | 6000 kv-a. |

*Effective line length is the length of the connected line on opposite side of ground relays from ground fault. (Effective in producing residual charging current through relay.)

the current in the potential coil is brought practically in phase with the potential by adding a resistor $R$, Fig. 2, in series with the potential coil. The vector relations in the relay are shown in Fig. 7. It should be pointed out that the current and voltage in the relay are zero except in case of a ground, thus permitting the use of a sensitive device.

*Scheme using Low-Tension Potential Transformers.* The relay scheme discussed so far necessitates the use of high-tension potential transformers, since the unbalance of the neutral voltages on the high-tension side is not transmitted to the low-tension side through a power transformer bank if the high-tension side of the bank is ungrounded.

Naturally, high-tension potential transformers involve a great expense on high-voltage systems. For this reason, another relay scheme was worked out which can be used in connection with low-tension potential transformers.[6] It necessitates complication of connections and great care in checking polarities, but it will bring about material savings in cost.

## Application

*System Connections.* The Consumers Power Company have a 140-kv., 60-cycle isolated neutral transmission system having a total connected length of approximately 380 mi. and extending from hydroelectric generating plants in the northern part of the state down along the eastern side through Saginaw, Flint,

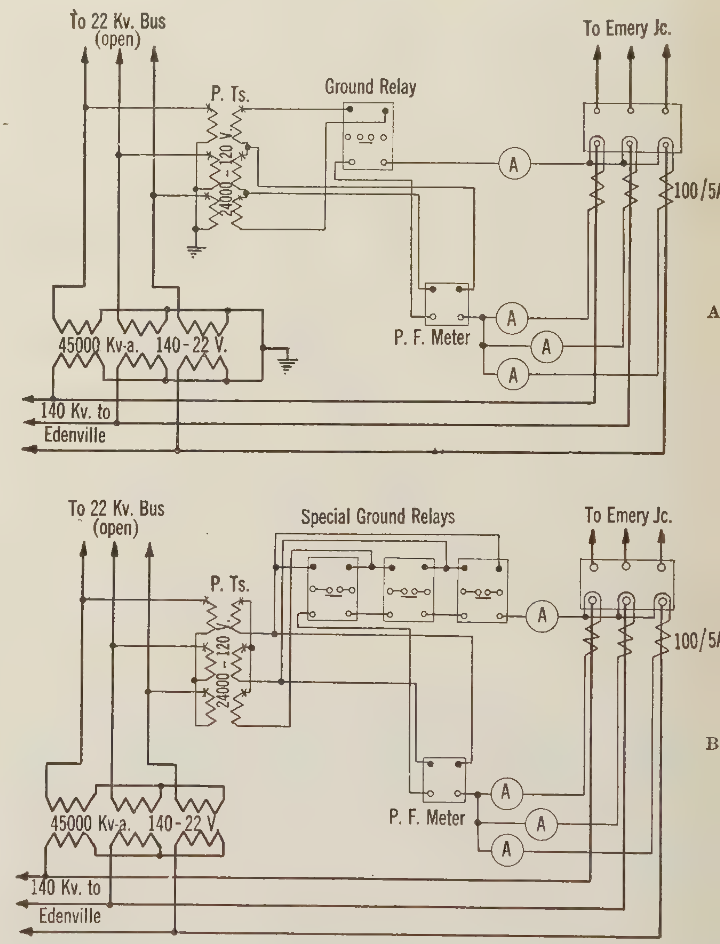


Fig. 11—Relay Schemes used for Ground Tests

A. High-voltage potential transformer scheme
B. Low-voltage potential transformer scheme

and across to Battle Creek. This is known as the "H-8" system and is shown in a simplified manner in Fig. 9. Power is supplied from hydroelectric generating stations in the Ausable River and the steam generating stations at Saginaw, Flint and Battle Creek. Important loads are served f om this transmission system at Saginaw, Edenville, Flint, Owosso, Lansing, Charlotte and the Battle Creek stations.

*Field Tests.* In connection with the application of

6. This scheme was developed in cooperation with Mr. H. A. Travers and details of it are given in the unabridged paper.

this ground relaying scheme, it was decided that a field test should be made to check the theoretical calculations of the amount and distribution of residual charging current under ground fault conditions and also to observe the actual operation of the special directional ground relays which had been developed. Fig. 10 shows the system connections, generating capacity, test connections and fault conditions during the tests. Power was supplied by hydroelectric generating stations on the Ausable River feeding through the 140-kv. lines to the Saginaw River Steam Plant and on to Edenville. The connected length of line and the generating capacity used during the tests are indicated Both solid and arcing ground tests were made, the latter conditions being obtained by connecting a line wire to approximately 300 ft. of wire lying on the ground.

Two different schemes of ground protection had been developed, one using high-tension potential transformers and the other using low-voltage potential transformers. Both schemes were tested out at this time and the detailed test connections used are shown in Fig. 11, A and B. The regular high-tension potential transformers were not available for these tests and therefore a large bank of $Y$-$Y$-connected, 140/22-kv. power transformers were used to step the voltage down from 140 kv. to 22 kv. The neutrals of this $Y$-$Y$ transformer bank were grounded when testing scheme No. 1, but not when testing scheme No. 2. In each case, 24,000/120-volt potential transformers were used to supply potential for the relays and they were connected $Y$-$Y$ for testing scheme No. 1 and $Y$-delta for scheme No. 2.

Four special type $C$ $R$ directional ground relays were provided, one for scheme No. 1 and three for scheme No. 2, together with various indicating meters at the Saginaw River Station. A standard 100/5-ampere, 15-kv. instrument current transformer was connected in the ground lead at the point of fault and a high speed graphic ammeter, having a roll speed of approximately nine in. per min., was used to give an indication of the actual amount of ground fault current obtained. The various tests were made as follows:

| Test no. | Relay scheme | Ground: Location | Ground: Nature |
|---|---|---|---|
| 1 | Low tension (No. 2) | Edenville | Solid |
| 2 | Low tension (No. 2) | Edenville | Arcing |
| 3 | High tension (No. 1) | Edenville | Arcing |
| 4 | High tension (No. 1) | Saginaw River | Solid |
| 5 | Low tension (No. 2) | Saginaw River | Solid |
| 6 | Low tension (No. 2) | Saginaw River | Arcing |

The results of the above tests were satisfactory and asummary of them is given in Table I.

Some line trouble in the nature of high-resistance intermittent grounds was experienced before and during the tests, which trouble was later found to be due to the line arcing into trees north of Saginaw. This somewhat affected the results, especially the accurate observation of current and voltage readings. It should be noted here that, judging from subsequent data on relay operations, during fault conditions, the actual ground currents obtained must have been within 10 to 20 per cent of the calculated values since the actual tripping time of the relays was very close to the calculated time. The test demonstrated that scheme No. 1, using high-tension potential transformers, will work satisfactorily with either a solid or with an arcing ground.

Because of the line trouble experienced, the test of the scheme using low-tension potential did not give conclusive evidence of satisfactory operation, although correct indications were observed. Therefore a further

TABLE I
SUMMARY OF RESULTS OF GROUND TESTS

| Test no. | Relay scheme | Test ground: Location | Test ground: Nature | $\phi$ | Trans. line Length M.: Total | Trans. line Length M.: Eff.* | Currents at relay: Line X | Line Y | Line Z | Residual: Test | Residual: Calc. | Total: Res. Test | Total: Cur. Calc. | P. F. % | Sec. Volts | Relay | Operation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | No. 2 | Edenville | Solid | Y | 128.9 | 89.2 | 80 | 190 | .. | 45 | 58 | 104 | 84 | 62 | $X-Y$ / 116 | Open | Closed | Closed |
| | | | | | | | Reversed relay current coil connections | | | | | | | | .. | Closed | Open | Open |
| 2 | No. 2 | " | Arcing | Y | 188.9 | 149.2 | 90 | 240 | 96 | 50 | 82 | 120 | 122 | 80 | 98 | Open | Closed | Closed |
| 3 | No. 1 | " | " | Y | 188.9 | 149.2 | 112 | 200 | 78 | 56 | 97 | 92 | 122 | 45 | 121 | Opened strong | | |
| | | | | | | | Reversed relay current coil connections | | | | | | | | .. | Closed strong | | |
| 4 | No. 1 | Saginaw | Solid | Y | 149.2 | 149.2 | 120 | 200 | 140 | 40 | 97 | 101 | 97 | 30 | Relay / 212 | Closed strong | | |
| 5 | No. 2 | " | Solid | Y | 149.2 | 149.2 | 80 | 112 | 85 | .. | .. | 62 | 97 | 95 | $X-Z$ / 110 | Open | Closed | Closed |
| 6 | No. 2 | " | Arcing | Y | 149.2 | 149.2 | 75 | 112 | 85 | .. | .. | Indef. | 97 | 100 | 103 | Indef. | Indef. | Indef. |

*Note: Effective line length is the length of the connected line on opposite side of ground relays from ground fault. (Effective in producing residual charging current through relay).

test of this scheme was made extending over a period of several weeks, this being in the nature of an operating test with the relays connected so that their operation under actual system conditions would be recorded. This test, which is described in the unabridged paper, proved the correctness of the scheme.

*Bushing Type Current Transformer Tests.* At the time the application of these ground relays was being studied, there was little information available regarding the actual ratio and phase-angle characteristics of bushing type current transformers, especially under conditions of low or unbalanced primary currents and high secondary burdens. The amount of residual charging current available is small even under the best conditions

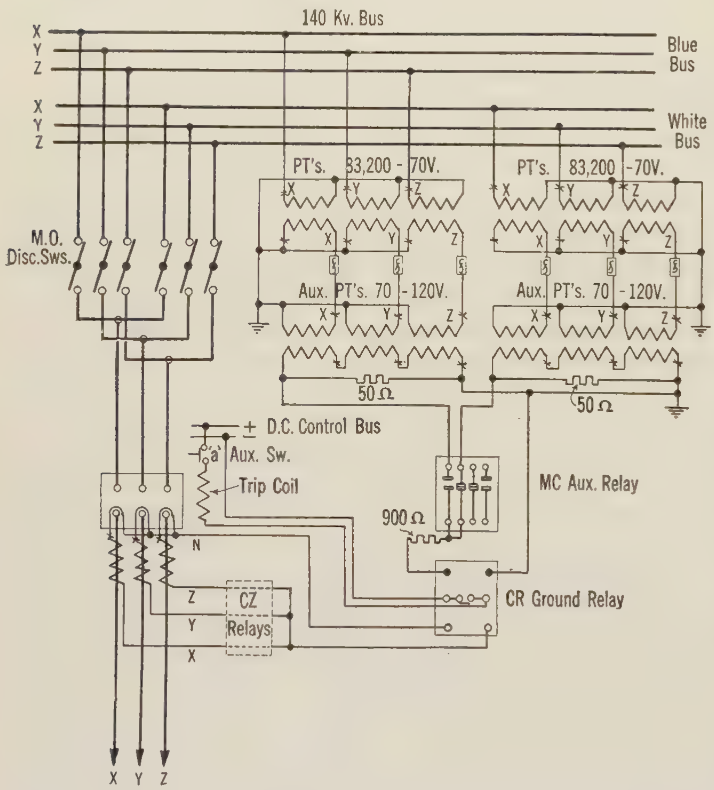


Fig. 13—Directional Ground Relay Protection using High-Tension Potential Transformers

and its phase relation is such that the phase-angle errors of the current transformers should be known, particularly for the low-tension relay scheme. The directional ground relays impose a considerable burden on the current transformers, it being in the nature of eight ohms or one volt—ampere per relay at the minimum tripping current. For these reasons, special ratio and phase-angle tests were made on several bushing type current transformers under conditions of primary currents and secondary burdens approximating those which were expected in service with the ground relays. The results of these and subsequent tests are given in the unabridged paper.

*Installations.* One type $C\ R$ directional ground current relay is used for ground protection on each of the 140-kv. lines at the Saginaw River Steam Plant and connected as shown in Fig. 13. The oil circuit breakers are equipped with three bushing type current transformers and the current coil of the ground relay is connected in the neutral circuit of the bushing current transformers. Two banks of high-tension potential transformers rated 83,200/69.2 volts and connected $Y$-$Y$ grounded are used, together with 70/120-volt auxiliary potential transformers connected $Y$-delta to furnish the potential for the ground relays. The auxiliary potential transformers are necessary because the high-tension potential transformers must be connected $Y$-$Y$ and used for other relaying and synchronizing purposes. The potential coils of the ground relays are connected inside the delta circuit of the auxiliary potential transformers. One set of potential transformers is connected to each 140-kv. bus and auxiliary relays are provided to automatically transfer the potential circuits of the relays from one set to the other in case either one is de-energized.

TABLE II
TOTAL RESIDUAL CHARGING CURRENT

| Transmission line section | Length | $I$ |
|---|---|---|
| Ausable to Saginaw | 149.2 | 97 |
| Edenville to Saginaw | 39.7 | 26 |
| Saginaw to Flint (H-8) | 41 (Av.) | 27 |
| Saginaw to Flint (K-11) | 41 (Av.) | 27 |
| Flint to Battle Creek | 111 | 72 |

A similar installation of directional ground relays and potential transformers is provided for the various 140-kv. lines at the Flint-Garfield Avenue Substation. The directional ground relays cannot be used at the end of a single line and therefore they are not installed at the present time at Edenville or Battle Creek. Also, no residual voltage relay is used at these stations since no high-tension potential transformers are available.

*Ground Current Calculations.* The amount and division of ground current flowing under various conditions of line-to-ground faults was calculated in order to determine the proper relay settings. These calculations were based on the line capacity and residual charging current formulas previously given. All the necessary circuit data are given in Fig. 9, except for the average height above ground, which is 50 ft. Therefore, for the lines on this particular system, $h = 600$ and $r_0$ (average) $= 18.2$. Substituting these values in the formulas:

$$\text{Capacity } (C) = \frac{0.03882}{\log_{10} \dfrac{2\,h}{r_0}} \times 10^{-6} = 0.0214 \times 10^{-6}$$

farads per mi.

Admittance $(Y) = 2\,f\,C = 8.06 \times 10^{-6}$ mhos per mi.

Residual charging current $(I) = E_n\,Y = 0.65$ amperes per mi.

The total residual charging currents for the various sections of transmission lines are given in Table II.

As previously mentioned, the division of residual

charging current depends on the transmission line lengths and connections. The calculated division of residual charging current and the relay operation for several assumed conditions of line-to-ground faults are given in Fig. 16, A, B and C. In Fig. 14A, a line-to-ground fault is assumed on the $H$-8 north line at Saginaw and the total residual charging current at the fault is 248 amperes; of this, 152 amperes pass through breaker No. 177 and the rest flow in the opposite direction. The current through breaker No. 177 further subdivides as indicated. The 152 primary amperes give 2.0 secondary amperes and with the relays set

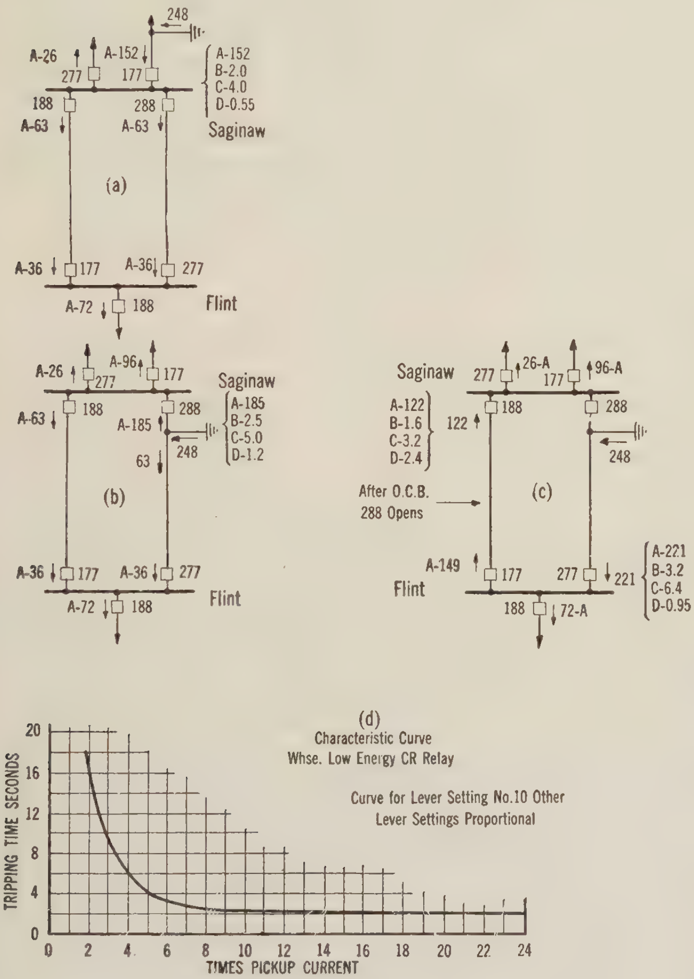


FIG. 14—DIVISION OF RESIDUAL CHARGING CURRENT UNDERGROUND FAULT CONDITIONS

on current tap 0.5 and lever No. 1, they will operate in 0.6 sec. as shown by their time—current characteristic curve, Figs. 14D. Figs. 14B and 16C show the division of residual currents in case of a line-to-ground fault on one of the Saginaw-Flint tie lines at Saginaw. Under such conditions and with the tie line relays set on current tap 0.5 and lever No. 3, the relays on breaker No. 288 at Saginaw will operate in 1.2 sec. and those on breaker No. 277 at Flint will operate in 2.15 sec., total time from occurrence of fault. The current and time settings used on all the relays are given in Table III.

The values of residual ground current obtainable are small and the relay current settings were therefore made as low as possible. The relays on each end of the Saginaw-Flint tie lines were set to operate on the inverse part of the time—current curve so as to operate selectively under all conditions. The time settings selected were such as will give a rather long time delay in order to allow minor flashovers to clear themselves before the relays operate. This helps to prevent disconnecting the lines unless serious trouble develops.

TABLE III
RELAY CURRENT AND TIME SETTINGS

| Circuit breaker | | Relay settings | |
|---|---|---|---|
| Station | Number | Current | Time |
| Saginaw | 177 | 0.5 Amp. | Lever No. 1 |
| " | 277 | 0.5 " | " No. 1 |
| " | 188 | 0.5 " | " No. 3 |
| " | 288 | 0.5 " | " No. 3 |
| Flint | 177 | 0.5 " | " No. 3 |
| " | 277 | 0.5 " | " No. 3 |
| " | 188 | 0.5 " | " No. 1 |

*Testing Directional Connections.* Each directional ground relay must be connected so that it will operate in the proper direction when a ground fault occurs on its particular line. The residual charging current has a 90-deg. phase relation with the residual voltage and it would be desirable to be able to test these relays by actually putting a ground on the line but this cannot be conveniently done on this system and therefore the proper conditions have to be approximated by an artificial similation of grounded conditions using normal voltage and load currents.

De-energizing one phase of the auxiliary potential transformers gives a potential across the ground relay terminals which will have the same relative phase relation as the residual potential across the relay terminals when the $X$-phase of the line is grounded. The relay should thus operate properly with this potential and with a current leading it by 90 deg. If actual load currents are used, the direction of power flow must be ascertained in order to determine whether the directional contacts of the relay should open or close under the test conditions.

The actual procedure used in testing the directional setting of these ground relays is described in the unabridged paper.

## OPERATION AND RESULTS

*Relay Operation.* Approximately 75 per cent of the operations of these ground relays during 1926 have been found to be definitely correct. The remaining 25 per cent of the operations were questionable, as no indication of trouble was found. In connection with the questionable cases of operation, it should be understood that with the isolated neutral system, a great many cases of insulator flashovers have occurred and cleared themselves before any serious system disturbance developed. With the trouble which was

experienced with potential transformer fuses blowing, there was always a question as to whether these fuses did not blow before the relays had a chance to operate in case of line trouble. Also, while these flashovers constitute a ground fault, the relays may operate before the damage to insulators or conductors is of sufficient magnitude to be noticeable on casual inspection.

Since the resistors were installed to prevent the fuses in the potential transformer secondary circuits from blowing,[7] there has been no questionable operation. Several definite cases of ground faults have been isolated by these relays, and we feel confident that they will continue to operate in this satisfactory manner.

A point to be particularly mentioned in connection with these relays is the necessity of keeping the system connected at all times in order to obtain as much residual charging current as possible. Formerly, during times of storm, the system was split up in order to isolate any possible cases of trouble. With this method of relaying, however, it is essential to keep the system all connected together, and this is favorable to the present load conditions, as it is frequently impossible to split the system due to need for all of the generating equipment on the line.

*Future Installations.* Due to the very favorable operation of the relays which are installed at the Saginaw River Steam Plant and Garfield Avenue Substation, it is planned to increase the number of installations on the system. At large substations where it is planned to use high-tension potential transformers, the present relay scheme will be used. At the smaller stations having no high-tension potential transformer, the relay scheme utilizing the low-tension potential transformers will be used. With this second scheme, it is much more difficult to obtain the correct directional setting, but after the relays are installed and adjusted, they should work satisfactorily. Within the next year, these ground relays will probably be installed on the 140-kv. lines at our Owosso, Charlotte and Blackstone substations.

7. See unabridged paper.

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**Abridgment of**

# The Electric Arc

BY K. T. COMPTON*
Non-member

***Synopsis.***—*DEFINITION OF ARC. An arc is a discharge of electricity, between electrodes in a gas or vapor, which has a voltage drop at the cathode of the order of the minimum ionizing or minimum exciting potential of the gas or vapor.*

*ARC CHARACTERISTICS. The relation of arcs to glow discharges and coronas is illustrated by discussion of "generalized" curve of the gas discharge characteristic. Empirical equations for arc characteristics are interpreted, and a dependence on the boiling temperature of the anode is shown. Seeliger's experiments on the transition from glow to arc, accompanied by the development of a cathode spot, show that the mechanism of the current at the cathode is fundamentally different in the two types of discharge.*

*CATHODE SPOT. An analysis based on heat conduction in the cathode shows that the cathode spot has no sharp thermal definition, but does have a sharp boundary if defined by visual brightness or by thermionic emission. The phenomenon of moving cathode spots presents the problem of accounting for the observed temperatures.*

*THEORIES OF CATHODE FALL. Compton's theory is based on space charge considerations and the assumption that the thickness of the fall space is equal to the electronic mean free path. Langmuir's theory differs from Compton's in assuming this thickness to be considerably less than a free path. Considerations of energy balance at the cathode definitely support Langmuir's rather than Compton's theory.*

*ENERGY BALANCE AT CATHODE. Calorimetric measurements permit an estimate of the fraction of the current at the cathode which is carried by electrons. Though uncertain, the data are accurate enough definitely to support Langmuir's theory and to indicate that, in many cases, thermionic emission of electrons from the cathode is supplemented by a "pulling out" of electrons by the electric field which is concentrated at the cathode surface.*

*Factors which determine the anode drop and the potential fall and ionization in the negative glow and the positive column are briefly discussed.*

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## Definition of Electric Arc

One is struck, in reading the literature of this subject, at finding no precise definition of an arc. This is due to the fact that although we readily distinguish common forms of arcs from sparks, flow discharges and coronas, yet there are graduations from one form to another so that the distinction is sometimes difficult to make. Child[1] describes an arc as "a continuous current of several amperes or more, passing through a gas and having a cathode drop which is comparatively small." Hagenbach[2] says, "In order to be able to define the arc, the cathode fall must be taken to be characteristic. As compared with the glow discharge, it is small . . . ."

The arc is characterized by a larger current and a lower voltage than any other type of gas discharge. The total voltage across the arc is the sum of (1) the cathode drop, which has a value characteristic of the gas; (2) the anode drop, which depends on the size and shape of the anode as well as the nature of the gas and

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1. For all numbered references, see Bibliography.

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its degree of ionization, and which may be positive or negative in sign; (3) the drop along the positive column, which is generally proportional to the length of the positive column and depends on the current and the nature and density of the gas; (4) a voltage drop, generally negative but usually small, between the region of the cathode fall and the beginning of the positive column. Of these parts it is only the cathode drop which appears to have a definite characteristic value; the other three may be altered or eliminated by altering the current, the pressure or the geometry of the arc path.

In view of these considerations, which will be amplified later, the following definition of an arc is proposed: *An arc is a discharge of electricity, between electrodes in a gas or vapor, which has a voltage drop at the cathode of the order of the minimum ionizing or minimum exciting potential of the gas or vapor.*

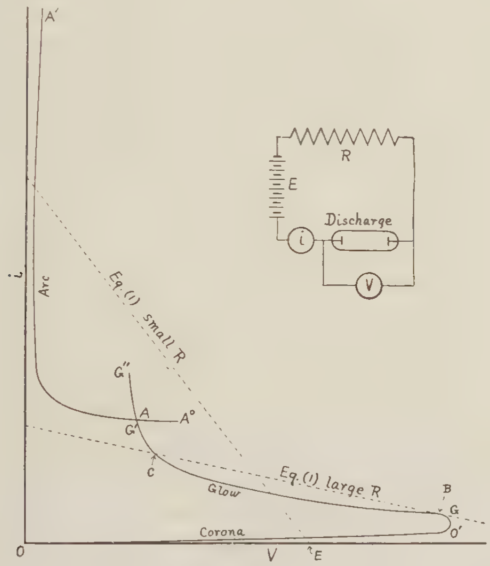

Fig. 1

It must be remembered, however, that there are transition stages between typical arcs and typical glow discharges which cannot be defined as either[3].

## Discharge Characteristics and Types of Discharge

The relation of the arc to other types of gas discharge is well illustrated by the generalized discharge characteristic.[4] The simplest gas discharge circuit consists of a source of e. m. f., $E$, a discharge between electrodes, $D$, and a series resistance, $R$, together with an ammeter and a voltmeter to measure the current $i$ and the voltage drop $V$ across the discharge. The external circuit characteristic is obviously

$$E = V + R\,i. \tag{1}$$

The nature of the discharge apparatus itself is given by an internal characteristic

$$V = f\,(i). \tag{2}$$

In Fig. 1 the external characteristic is represented by a straight line of slope $-1/R$ and voltage intercept $E$. The internal characteristic is represented by the curve $O\,O'\,G\,G'\,A\,A'$. The possible values of current and voltage are given by the intersection points of these curves (1) and (2).

If, keeping $R$ constant, $E$ is gradually increased from an initial value $O$, the current is first small and the volt-ampere characteristic is positive. This is the region of corona, or Townsend currents $O\,O'$. Beyond $O'$ the current rapidly increases, the volt—ampere characteristic is negative and we have the region of the glow discharge $G\,G'$. The current jumps discontinuously from point $B$ to point $C$ on the curve. Obviously, the entire glow discharge may be skipped over if the resistance $R$ is small, *i. e.*, the slope of the line $E\,B\,C$ large. In this case the discharge passes abruptly from the corona to the arc type. On the other hand, if the resistance $R$ is very large and the line $E\,B\,C$, almost horizontal, the entire change from corona through glow to arc may be passed through continuously.

At $G'\,A$ there is a transition from glow to arc. Sometimes this transition is gradual and sometimes abrupt, in which cases the curve is rounded or sharp at the transition region $G'\,A$. If the transition is abrupt there is evidence that the glow and arc characteristics intersect and may be prolonged as $G'\,G''$ and $A°\,A$, and it is then possible to have either an arc or a glow discharge at the same voltage, or at the same current, and we have, within a small range, the anomalous situation of a low discharge carrying larger currents than the arc at the same voltage.

In general, it is possible to determine the entire discharge characteristic of any given type of discharge apparatus by using sufficiently large ballast resistance, $R$, and correspondingly large e. m. f., $E$. Once this characteristic is known, the various changes in the discharge, which will be found when any variations of $E$ or $R$ are made in the circuit, may be predicted.

In this connection, mention only may be made of a very complete discussion of the question of *stability* of gas discharges given by Dallenbach[5] and summarized by Bar[6]. The fundamental condition for stability[7] is that $-\dfrac{d\,V}{d\,i} < R$, *i. e.*, that the slope of the internal characteristic curve (2) be greater than that of the external characteristic curve (1). In addition to this, inductance and capacity and inertia of ions must be taken into consideration.

## Fundamental Importance of Phenomena at Cathode

All lines of evidence indicate that the essential feature of an arc is the emission of electrons from the cathode which produces sufficient ionization of the surrounding gas to give a positive space charge just outside the cathode, thus facilitating ionization and permitting a

large, generally saturation, electron emission at relatively low voltage. All other characteristics of arcs appear to be either consequences of this emission or prerequisites to it under the particular physical conditions in which the arc is produced. Theoretically *any* mechanism or process for supplying electrons from a cathode in sufficient numbers to produce at low voltages of the order of the minimum critical potentials of the gas enough ionization to give a positive space charge should suffice to maintain an arc. Actually, however, only two emission processes seem capable of supplying electron emission in sufficient amount: thermionic emission and the pulling of electrons from the cathode by the large field in the cathode fall space, or a combination of these two. J. J. Thomson[8] and Stark[9] first suggested the former theory and Langmuir[10] the latter one. The present evidence, some of which we shall now review, points to the truth of each in particular cases and generally to a combination of both.

### Cathode Spot: Area, Temperature, Current Density

In all arcs except those in which the cathode has small area and cannot lose heat rapidly by metallic conduction (as in arcs with hot filament cathodes as used in Tungar rectifiers) or those whose temperature is maintained primarily by external heating the current at the cathode is concentrated in a small area called the "cathode spot." To study the physical condition of the cathode, we must therefore examine this cathode spot. This is extremely difficult, however, owing to its small size, its frequent rapid motion, and the difficulty in defining it. Until very recently there were no measurements of the area of the cathode spot except in the case of carbon arcs, but recently measurements also have been made on several metallic arcs. These results are shown in Table I.

In the case of carbon, the spot is stationary and the chief source of error is probably in the measurement of the photographic plate or the interpretation of visual observations. It should be remarked, moreover, that different grades of carbon give different results, presumably due to the effect of alkaline impurities on the amount of thermionic emission. In the metal arcs, the spot usually wanders rapidly, so that Güntherschulze photographed it as a band after reflection from a revolving mirror. Seeliger[11] was unable to repeat

TABLE I

| Arc | Current density amp. per cm.² | Observer | Reference |
|---|---|---|---|
| Carbon in air..... | 210 | Reich | *Phys. Zeits.* **7**, 73, 1906. |
| | 318 | Granquist | *Phys. Zeits.* **7**, 79, 1906. |
| | 470 | Guntherschulze | *Zeits.f. Phys.* **11**, 71, 1922. |
| Mercury vacuum. | 4000 | " | *Zeits.f. Phys.* **11**, 74, 1922. |
| Iron in air........ | 7200 | " | *Zeits.f. Phys.* **11**, 74, 1922. |
| Tungsten in air... | 3200 | Brauer | *Ann. d. Phys.* **60**, 95, 1919. |
| | 700 | Nottingham | To be published. |
| Cadmium in air... | 5000 | " | To be published. |

Güntherschulze's work. Nottingham has used an accurate photometric method of measuring his photographic plates, but did not use a revolving mirror; the internal evidence in his work, however, justifies considerable confidence in its correctness.

Similarly, the temperature of the cathode spot is not very accurately known. The best determination for carbon arcs is probably that of Reich,[12] who gives 3413 deg. *K*, although other observers give values from 2903 deg. *K*. to 3593 deg. *K*[13]. Hagenbach and Langbein[18] give for iron 2430 deg. *K*., nickel 2365 deg. *K*., tungsten 3000 deg. *K*., silver and copper below 1800 deg. *K*. Nottingham, however, has found fusion of tungsten in the cathode spot, which would prove its temperature to be at least 3643 deg. *K*. It is quite possible that the small size of cathode spots has led to an underestimate of their maximum temperature.

The cathode spot of a mercury arc has been estimated as between 2000 and 3000 deg. *K*. on account of a continuous spectrum emitted from it and ascribed by Stark[19] to local high temperature in spite of the much lower boiling temperature of mercury, thus supporting

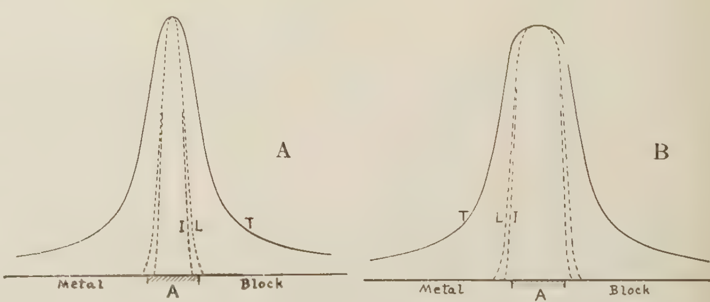


Fig. 2

his theory of the thermionic origin of the electron emission from the cathode. This spectrum, however, may be otherwise accounted for, and there is no certain evidence that the temperature is so high. Seeliger[11] applied Knudsen's equation to rate of evaporation as a function of temperature, using Güntherschulze's measurements of rate of evaporation,[14] and calculated a lower limit of 673 deg. *K*. We shall present evidence below, however, indicating that the mercury loss measured by Güntherschulze was partly in the form of a spray rather than true evaporation, so that Seeliger's lower limit should be considerably less than 673 deg. *K*. Thus we really know very little regarding the temperature of the cathode spot n mercury arcs.

A very illuminating study of the theory of the cathode spot has been made by Seeliger.[11] Consider first a case where heat is liberated at a rate $Q$ per cm.² at a fixed circular area $A$ on the plane surface of a metal block of indefinite extent. This corresponds roughly to the heated region of a cathode surface. Because of heat conduction in the metal, a temperature gradient is set up radially outward on the surface of the block as well as into its depth. The final steady surface tempera-

ure distribution is calculated by the known theory of heat conduction and is found to be of the form shown by the curve $T$, Fig. 2A. It is quite obvious that there is nothing in the nature of a sharply defined "hot" spot.

The spot is observed, however, by means of the light radiation from it, and it is well known that visual brightness $L$ increases as a high power of the temperature $T$, being given approximately by the relation

$$T = \frac{11230}{5.367 - \log L} \qquad (3)$$

in the temperature range involved here. From this, and assuming that the maximum temperature in curve $T$ is 3300 deg. $K.$, the visual brightness curve $L$ is found to be as shown. This does limit quite a sharply defined region which does not differ much in area from $A$. Thus, as seen by the eye, the cathode spot is sharply defined.

Electrically, however, it is neither the temperature nor the brightness but the thermionic emission which is important, and this may be calculated as a function of temperature by Richardson's equation

$$I = A\,T^{1/2}\,\epsilon^{-b/T} \qquad (4)$$

Taking $b = 6\,(10)^4$ for carbon, this leads to curve $I$ for the current density of thermionic emission from various regions of the spot. Here again, the spot is quite sharply defined and has approximately the dimensions of $A$, although it is somewhat smaller than the "visual" spot.

It is certain that considerations such as these are involved in stationary cathode spots, especially if the electron emission is primarily of thermionic origin. The problem is further complicated, however, in cases where evaporation or sublimation tends to cool the cathode, and of course electron emission is itself a cooling process. These cooling agencies, acting in addition to conduction through the body of the cathode, must tend to limit the temperature in the hottest regions of the spot, and thus to alter the distributions of Fig. 2A to something like the form of Fig. 2B, which helps to explain the fact that the area of the spot is so nearly directly proportional to the current.

In the case of metallic arcs whose spot wanders rapidly over the cathode surface, there is a real difficulty in explaining the high temperature of the spot, since the time available for heating is very short. In a mercury arc, for instance, the spot frequently wanders at a rate of at least 300 cm. per sec.[15,16] and may move 30 times this fast. Güntherschulze[17], Stolt[16] and Seeliger[11] have attempted to calculate the maximum possible rise in temperature if all the energy $i\,V_c$ liberated at the cathode goes into the metal and is carried away by heat conduction into the body of the cathode. Both calculations are rough approximations and they lead to opposing conclusions; *i. e.*, Güntherschulze concludes that the cathode spot even in mercury arcs rises to temperatures above 2000 deg. cent., while Seeliger and Stolt conclude that the temperature rises to only a few hundred degrees in mercury and copper arcs. The evidence is that Güntherschulze's conclusion is right, for at least in copper, the metal is found to be fused where the hot spot passes, although both Seeliger and Stolt criticize his computations. It is difficult to estimate the value of these computations, not only because of uncertainty regarding the data but also because the spot may not wander continuously, but jump from point to point, remaining at each point long enough to heat it.

It is evident from this brief survey that in spite of the attention which has been focussed on the cathode spot since its crucial importance in the theory of the arc has been realized, there is as yet no agreement as to whether the cathode spot *always* reaches such temperatures as to warrant a purely thermionic explanat on of the electron emission from it.

## Thermionic Emission from the Cathode

Table II gives thermionic emission values calculated from Richardson's equation (4). In comparing these values with current densities at the cathode spot in arcs, certain facts should be kept in mind. The emission values for carbon were given by Langmuir[18] for carbon as pure as could be obtained and with great care to avoid contamination. Such purity is utterly impossible in arc carbons, and the impurities which are known to be present are such as to increase the emission very considerably. An upper limit for arc carbons would be the values given for lime-impregnated carbon.[19] The actual thermionic emission from an arc carbon must lie between the values 26.7 and 4400 amperes per cm.[2] This makes it evident that much and possibly practically all of the arc current, (see Table I) is simply thermionic emission of electrons from the cathode. Similarly, in the case of the tungsten arc in air, the thermionic emission at the temperature of the cathode spot is adequate to account for the arc current, if Nottingham's values are correct.

TABLE II

| Carbon $A = 1.49\,(10)^{25}$ $b = 48{,}700$ | | Impregnated carbon $A = 3.3\,(10)^{26}$ $b = 42{,}000$ | | Tungsten $A = 1.55\,(10)^{26}$ $b = 52.500$ | |
|---|---|---|---|---|---|
| $T$ deg. $K.$ | Amps. per cm.$^2$ | $T$ deg. $K.$ | Amps. per cm.$^2$ | $T$ deg. $K.$ | Amps. per cm.$^2$ |
| 2700 | 1.9 | 2700 | 500 | 2400 | 0.365 |
| 3000 | 13.2 | 3000 | 2390 | 2800 | 8.98 |
| *3140 | 26.7 | *3140 | 4400 | 3200 | 96.9 |
| 3300 | 54.7 | | | 3540 | 509 |
| 3500 | 127 | | | *3640 | 977 |

The most accurate identification of arc current with thermionic emission from the cathode is obtained in arcs from a small non-vaporizing cathode, such as in Tungar rectifiers or Pointilite lamps in which there is no "hot" spot, but the entire cathode is at practically uniform temperature. In these cases, the temperature may be measured with an optical pyrometer and the thermionic emission current rather accurately estimated. In such

cases, the arc current is generally found to be accounted for by thermionic emission,[20] although in very intense arcs in gas at high pressure the arc current is somewhat larger than the calculated thermionic emission.

In the case of arcs from more easily volatilized cathodes the data, as we saw above, are too uncertain to support any very positive statement regarding the adequacy or inadequacy of thermionic emission in accounting for the arc currents. On the whole, the writer is inclined to the opinion that in these cases the ordinary thermionic emission is increased by an effect of the intense electric field at the cathode in actually *pulling electrons away from the cathode* which would not otherwise be emitted. It is significant that some agency in addition to thermionic emission appears to be needed to account for arc currents in just those cases in which conditions for such a "pulling out" effect would be most anticipated.

### Development of an Arc

Seeliger[21] has recently made an instructive experiment on the development of an arc from a glow discharge, and the relation of this to the formation of the cathode spot. He used a very high resistance to stabilize the discharge and very pure electrodes, and followed through the variations in current density as the total discharge current was increased, beginning with a normal glow discharge covering only part of the cathode. The results are shown diagrammatically in Fig. 3.

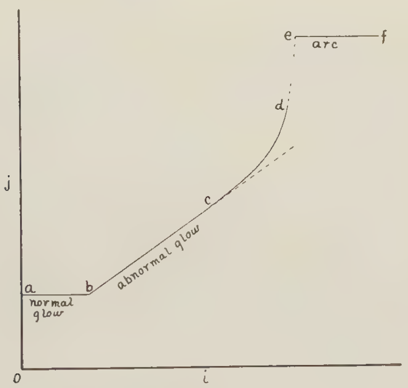


Fig. 3

In interval, $a\ b$, the current density was constant, the cathode fall of potential was constant at about 300 volts, and the glow did not completely cover the cathode. At $b$ the glow completely covered the cathode. Further increase in current was accompanied by increase in current density and large increase in the cathode drop, which may rise to several thousand volts. At $c$ there was first observed a tendency for the cathode glow to concentrate into a hot spot, which tendency increased with further increase in current. Simultaneously the current density increased at an accelerated rate, while the cathode drop began again to diminish. At the point $d$, the cathode drop had fallen to a value less than the original normal cathode drop, and it was falling so fast and the current density was rising so fast that the series resistance was insufficient to stabilize the discharge and it passed abruptly to condition $e$, from which point on the discharge was a true arc, the glow was replaced entirely by the hot spot, and the cathode drop was in the neighborhood of 10 volts.

This illustrates the fact that the mechanism of current transfer in the glow and arc discharges is quite different. In the glow discharge the current at the cathode is carried principally by positive ions, and the electron emission from the cathode is "secondary" emission due to positive ion bombardment and photoelectric action. In the cathode fall space the number of electrons involved in carrying the current increases rapidly, through impact ionization, with distance from the cathode.[22] In the arc discharge the current at the cathode is carried principally by electrons, which are probably liberated thermionically, assisted by the "pulling out" action of the field, and sufficient ionization occurs outside the region of cathode fall to give a positive space charge which concentrates the field at the cathode surface and may supply considerable heat by ion bombardment. The thickness of the cathode fall space in the arc is certainly thousands of times smaller than that in the normal glow discharge.

### Compton's Theory of Current at Cathode[23]

The existence of the cathode fall of potential is proof that the space charge near the cathode is positive, *i. e.*, that the concentration of positive ions exceeds that of electrons. Let $i$ be the electron current density and $J + j$ be the positive ion current density. $j$ is that part of the positive ion current which just neutralizes the space charge of the electrons, and $J$ is the excess, which accounts for the positive space charge, whose density we shall call $\rho$. By Poisson's equation,

$$\frac{d^2\,V}{d\,x^2} = -\,4\,\pi\,\rho = -\,4\,\pi\frac{J}{v}, \tag{5}$$

where $v$ is the average velocity of advance of the positive ions in the field $-\,d\,V/d\,x$ and is given approximately by

$$v = \sqrt{\frac{\pi}{2}}\sqrt{L\frac{e}{M}\frac{d\,V}{d\,x}}, \tag{6}$$

in which $M$ is the mass and $L$ the mean free path of the ions. The solution of this equation gives the cathode drop

$$V_c = \frac{3}{5}\,\frac{(6\,\pi)^{2/3}\,J^{2/3}\,c^{5/3}}{\left(\frac{\pi}{2}\,\frac{e}{M}L\right)^{1/3}} \tag{7}$$

We are entirely without experimental evidence regarding the thickness of the cathode fall space in arcs, except for the knowledge that it is extremely small. It seems certain that it does not exceed the electronic mean free path $l$, since the electrons have their best chance to ionize at their first impact owing to the fact that electric

intensity diminishes with distance from the cathode. In the present theory it is assumed that $c = l$, though it may be that this is an upper limit. Now the ionic free path $L$ is $\sqrt{2}$ times the molecular free path $\lambda$, since the ions have a higher order of speed than do the molecules. Also, the electron free path $l$ is $4\sqrt{2}$ times $\lambda$, and hence 4 times $L$, owing to the negligibly small dimensions of an electron. Thus, writing $c = l$ and $L = l/4$, and solving equation (**7**) for $J$, we find

$$J = \frac{1}{12}\left(\frac{\pi}{2}\frac{e}{M}\right)^{1/2}\left(\frac{5}{3}V_c\right)^{3/2}\frac{1}{l^2} \text{ in c. g. s. units.}$$

$$= 0.76\,(10)^{-7}\frac{V_c^{3/2}}{M^{1/2}\,l^2} \text{ in amperes per cm.}^2\text{, with } M \text{ in ordinary molecular weight units.} \qquad (\mathbf{8})$$

Consider now that part of the positive ion current density $j$ required to neutralize the electron space charge, $j$ and $i$ being proportional to the mean rates of advance of ions and electrons, respectively, and their ratio may be shown to be approximately

$$\frac{i}{j} = 4\sqrt{2}\sqrt{\frac{M}{m}}, \qquad (\mathbf{9})$$

which was the relation taken in the original statement of the theory[23], but derived there in a manner quite inconsistent with the actual physical conditions in the fall space. We shall use equation (**9**), therefore, in the belief that it is at least a fair approximation to the requirements of the theory.

Expressing currents in amperes, potential drop in volts and ionic mass $M$ in ordinary atomic units, we have the results of this theory expressed by the equations:

$$\left.\begin{array}{ll} \text{Total current density} & I = i + j + J \\ \text{Neutralizing current density} & i = 242\sqrt{M}\,j \\ \text{Space charge current density} & J = 0.76\,(10)^{-7}\dfrac{V_c^{3/2}}{M^{1/2}\;l^2} \end{array}\right\} \qquad (\mathbf{10})$$

*Applications: Carbon Arc.* At atmospheric pressure and 3300 deg. $K.$, which is close to the cathode temperature $l = 0.66\,(10)^{-3}$ cm., $V_c$ is given as about 8.6 volts[24], although no determination by a reliable method has ever been made, and the true value is probably several volts higher. Substitution in equation (**10**) gives $J = 1.6$ amperes per cm.$^2$ Since the total current density $I$ is of the order of 320 amperes per cm.$^2$ [25] $J/I = 0.005$. Similarly $j/I = 0.001$. Thus altogether about 0.006 of the total current is carried by positive ions.

*Mercury Arc.* The vapor density at the cathode is of the order of an atmosphere[26] and its temperature is at least 400 deg. $K.$, and may reach 2000 deg. $K.$, although reasons are given later which weigh against this high value. We shall not be far wrong as to order of magnitude if we take 600 deg. $K.$, which gives $l = 0.000040$ cm. $V_c$ lies between 5.5 and 10.3, and is probably about 8.6. This leads to $J = 162$ amperes per cm.$^2$ Güntherschulze finds the current density $I$ at the cathode to be 4000 amperes per cm.$^2$, whence $J/I = 0.040$. Similarly $j/I = 0.0003$. Thus about 0.04 of the total current is carried by positive ions.

Other cases agree in indicating that only a small fraction of the total current at the cathode is carried by positive ions.

A test of this theory is afforded by comparing these calculated values for the fraction of current carried by positive ions with the values calculated from considerations of thermal equilibrium at the cathode. Before doing this, however, we shall consider an alternative theory of the cathode fall space which has been proposed by Langmuir.

### Langmuir's Theory of Current at Cathode[10]

On this theory, the cathode fall space is simply the positive ion sheath produced around the cathode by the incoming positive ions. If it is assumed that the positive ions traverse this fall space without colliding with gas molecules, *i. e.*, if $d < l$, the space charge equation of Child[27] and Langmuir[28] may be applied in the form,

$$J = \frac{\sqrt{2}}{9\pi}\sqrt{\frac{e}{M}}\frac{V_c^{3/2}}{d^2} \text{ in c. g. s. units}$$

$$= 0.543\,(10)^{-7}\frac{V_c^{3/2}}{M^{1/2}\,d^2} \text{ in ordinary electrical and molecular units.} \qquad (\mathbf{11})$$

This does not appear to differ much from equation (**10**) of Compton's theory, but in reality it may be quite different since it does not assume $d$ to be equal to the electron free path $l$, but leaves $d$ undetermined. In order to use this equation, information from some other source must be obtained regarding either $J$ or $d$.

Two courses are open for finding independently the positive ion current density, $J + j$, in order to test Compton's theory or to complete the information necessary for Langmuir's theory. $J + j$ may perhaps be measured directly by Langmuir's exploring electrode method[29], although this has never been done near the cathode and presents experimental difficulties, or it may be calculated from considerations of thermal equilibrium at the cathode, as follows:

### Energy Balance at Cathode[30]

Let $f$ be the fraction of the current at the cathode which is carried by electrons and $1 - f$, that carried by positive ions. Then, per ampere of current, we have the following rates of heat development, in watts:

A. *Heating of Cathode.* (1) By incoming positive ions, which fall through the cathode drop $V_c$, $(1 - f)(V_c + \varphi_+)$, where $\varphi_+$ is the heat of neutralization of positive ions at the surface of the cathode; (2) by outgoing electrons, some of whose energy may be returned to the cathode, $[f\,(V_c - (1 - f)\,V_i]\,F$; here $f\,V_c$ is the

energy gained by the electrons in the cathode fall space, $(1 - f)\ V_i$ is the energy of these electrons which is used in ionizing the gas whose ionizing potential is $V_i$, and $F$ is the fraction of the remaining energy which returns to the cathode in the form of radiation, etc.; (3) by heat supplied by an external heating source, if there be one, $H$.

B. *Cooling of Cathode.* (1) By escape of electrons, $f\ \varphi_-$, where $\varphi_-$ is the electron "work function," or heat of evaporation; (2) by conduction through the body of the cathode, $C$; (3) by gaseous conduction and convection, $C'$; (4) by radiation, $R$; (5) by evaporation of cathode material, $E$.

Grouping all these items, we find the equilibrium condition to be given by

$$f = \frac{V_c + \varphi_+ - F\ V_i + H - C - C' - R - E}{V_c + \varphi_+ + \varphi_- - F\ (V_c + V_i)} \qquad (12)$$

An experimental determination of the factors in this equation should therefore permit a calculation of the fraction $f$ of the current at the cathode which is carried by electrons. Let us consider the various terms in this equation:

The cathode fall of potential $V_c$ in various arcs has been measured with the following typical results:

TABLE III

| Arc | $V_c$ (volts) | Reference |
|---|---|---|
| Carbon in air (current $I$) | 7.6 + 13.6/$I$ | (24) |
| Carbon (impregnated) in air | 8.5 | (31) |
| Magnetite in air | 13.9 | (32) |
| Copper in air at reduced pressure | 13.7 | (32) |
| Mercury in vacuum | 5.27 | (33) |
| *Argon gas and heated non-vaporizing cathode | 11.6 | (34) |
| *Helium gas and heated non-vaporizing cathode | 20.0 | (35) |
| *Mercury vapor and heated non-vaporizing cathode | 5.5 | (35) |

As all values except those marked* were obtained by the old probe method which is known to give incorrect results,[29] they are only approximate and are probably several volts too low. More accurate values are greatly needed.

The heat of neutralization, or condensation, of positive ions $\varphi_+$ was formerly calculated from a theoretical relation $\varphi_+ = V_i + L - \varphi_-$ derived by Schottky and von Issendorff[36] and by Compton.[30] Recent experimental measurements[37] have shown that the true value is much less than this, and nearly zero. Compton and Van Voorhis[38] give reasons for modifying the above equation to the form

$$\varphi_+ = r\ V_i + (L) - \varphi_-, \qquad (13)$$

where $r$ is a "radiation factor" a little less than 0.5, and $L$ is the latent heat of condensation of the neutralized ion on the electrode, in case the ion remains there deposited. If the material of the ion does not remain on the electrode after neutralization, $L$ is to be omitted from equation (**13**).

In this connection, the writer would suggest that the luminosity of the cathode in mercury arcs, which has been taken to indicate high local temperatures exceeding 2000 deg. $K$., may be simply this radiation accompanying ion neutralization at the cathode surface, and showing as a continuous spectrum because of the intense field at the surface.

The ionizing potential $V_i$ is accurately known for most gases and vapors.

The fraction $F$ of the excess energy of the electrons which is returned to the cathode is unknown. It cannot exceed 0.5. It is probably nearer 0.0.

$H$, $C$, $C'$, $R$ and $E$ may all be measured or computed. In considering the cooling $E$ by evaporation of cathode material, one must be cautious, however, since there is evidence in cases like the mercury arc that not all material lost is by true evaporation, but part of it is by mechanical loss as a "spray" which does not contribute to the cooling.

Evidently our present knowledge and our experimental technique are too limited to permit us to use equation (**12**) for accurate results. It may be used, however, to show orders of magnitude and to set certain upper and lower limits which permit us to draw some important conclusions.

*Applications: Carbon Arc.* Take, for a 10-ampere arc, $V_c = 9.0$ volts, $\varphi_- = 3.9$ volts, $\varphi_+ = 0$, $V_i = 16$ volts. A rough estimate of conductivity loss gave $C = 0.04$ volt. Net loss by radiation, calculated as if cathode and anode hot spots were black body radiators at 3140 deg. $K$., and 3700 deg. $K$., respectively, gave $R = 0.75$ volt. $E$ is relatively small, and so is $C'$, provided the arc is not cooled by an air blast. With these values we find

$$f = 0.64, \text{ assuming } F = 0$$
$$f = 0.63, \text{ assuming } F = 0.25$$

$f$ could be raised as high as 0.70 by neglecting *all* heat losses, $C + C' + R + E$, which is clearly an upper limit. No reasonable value of $\varphi_+$ differing from 0 would produce much change in $f$. The assumed value of $V_c$ is probably several volts too small, but no reasonable increase would increase $f$ greatly; $\varphi_-$ could only be given a smaller value if the electrons were pulled out of the cathode by the field rather than spontaneously emitted thermionically, and we have previously seen that no *large* effect of this kind can be important in the carbon arc. We thus seem forced from energy considerations to conclude that the fraction of current carried by electrons at the cathode is of the order of 60 to 70 per cent, rather than 99.4 per cent as predicted by Compton's theory. The fact that an earlier calculation[30] appeared to support Compton's theory was due, first, to the use of a value of $\varphi_+$ now known to be inadmissable[42] and second, to the use of an impossibly high value for $F$.

*Mercury Arc.* Recent experiments by Güntherschulze[39] give apparently accurate data for most of the quantities involved, except for minor corrections

pointed out by Seeliger[11] and included here. The data are, in watts (volts) per ampere of arc current, $C = 2.68$; $E = 2.8$ to $3.9$, depending on the assumed temperature of the cathode spot; $R = 0.04$. Taking $\varphi_- = 3.9$, $V_i = 10.4$, $\varphi_+ = 0$, $V_c = 8.6$ volts, knowing $C'$ to be negligible and $H$ zero, and assuming $F = 0$, we find $f = 0.25$ to $0.16$. If $F$ is taken to be greater than zero, $f$ becomes still smaller.

Even if cooling by radiation $R$ and evaporation $E$ is entirely neglected, which could only be justified if *all* mercury were lost from the cathode mechanically rather than by evaporation, and even if the cooling $\varphi_-$ by electron emission were neglected, which would be justified if the emission were due entirely to the "pulling out" effect of the field, still equation (**12**) gives only $f = 0.70$. In any case, therefore, the fraction of current carried by electrons must be less than 70 per cent, whereas Compton's theory predicted 96 per cent.

### Conclusions

From this consideration of energy balance at the cathode, therefore, it would appear that Compton's assumption that the thickness of the cathode fall space is equal to the electron mean free path is incorrect, and that this thickness is much smaller. If it is much smaller, the positive ions must move through it generally without colliding, and we have exactly the space charge condition leading to equation (**11**) of Langmuir's theory. We must therefore consider the evidence as strongly supporting Langmuir's theory.

Further than this, these energy considerations lead us to some conclusions regarding the mechanism of electron emission from the cathode of a mercury arc. Since almost certainly the cathode drop does not exceed the ionizing potential $V_i = 10.4$ volts, it is obvious that no electron can ionize more than once near the cathode. The fraction $f$ cannot, therefore, be less than 0.5 and could only be that small in case the probability of ionization were unity, which cannot be so. From this consideration, $f$ must *exceed* 0.5. An examination of equation (**12**) in connection with Güntherschulze's data shows that a value of $f > 0.5$ can only be obtained if $\varphi_- < 3.9$ and $E < 2.8$ by large margins. In other words, the field at the cathode surface acts to pull out electrons which would not otherwise be liberated,[40] and some of the mercury is lost from the cathode mechanically, rather than by evaporation. The former of these possibilities was suggested by Langmuir, whose measurements of positive ion current densities led him to estimate the field at the cathode of a mercury arc to be of the order of $10^6$ volts per cm. In cases where two arc types exist, as appears for tungsten in Table I, it is likely that one type is that in which thermionic emission predominates while in the other type this plays an insignificant role.

### Conditions Just Beyond the Cathode Fall Space

This region, generally called the negative glow, is a region in which the concentration of ions is maximum. The electric field is of minimum strength and is often reversed in direction, the current being by diffusion of electrons in the direction of decreasing concentration[39,41]. Probably much of the radiation from this part of the arc is the result of recombination of ions and electrons[42].

### Conditions in the Positive Column

Here ionization occurs to just a sufficient extent to balance the loss of ions by recombination or diffusion to the walls, if the arc be enclosed. This ionization may be produced thermally, by electron impact, photoelectrically, or by a combination of these. There are reasons for ascribing much of it to high temperature in the carbon arc[30], while this certainly plays no role in the mercury arc, where the ionization is due to electron impacts, probably of a cumulative nature. The light from the positive column is almost certainly due to excitation rather than to recombination[42].

### Conditions at the Anode

The anode drop in potential may be positive or negative according to conditions first explained by Langmuir and Mott-Smith[29] as follows: Surrounding the anode is an atmosphere of ions and electrons moving with more or less random motion. If, in this random motion, the excess of electrons over positive ions striking the anode would be greater than the total current in the circuit, then a negative, or reverse, anode drop is set up so as to hold back enough electrons to keep the current to the value demanded by the constants of the circuit. On the other hand, if the number naturally striking the anode is insufficient to carry the current, then a positive anode drop is set up so as to draw in more electrons. From these considerations, it is evident that anode drop decreases with increasing anode area and with increased ion concentration, as can be obtained by using a hollow anode or by promoting ionization near the anode.

The heating of the anode depends on three fractors: (1) the heat of condensation of electrons $\varphi_-$; (2) the average energy $\overline{V}_-$ of the electrons in their initial random motion; (3) the anode drop $V_a$, if this be positive. Although this subject has been studied calorimetrically[43] and the order of magnitude of these predictions always verified, thus far only Van Voorhis[37] has measured all the quantities necessary to make an accurate quantitative test, which has exactly verified the above statements.

From the preceding discussion it will be seen that much progress in the understanding of arc phenomena has been made during the past few years, and that there are at present numerous possibilities for further experimental research, guided by theoretical considerations.

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### Abridgment of

# Catenary Design for Overhead Contact Systems

BY H. F. BROWN[1]

Member, A. I. E. E.

THE rational mechanical design of any overhead contact system must be based upon certain fundamental rules of mechanics, usually those dealing with statics, or forces in equilibrium, applied to the physical characteristics of the track alinement. Theoretically a problem for the civil engineer, the general solution and detailed application of the design has been assigned to the electrical engineer in most cases, as the number of papers presented on this subject would indicate.

It is now generally conceded that railroad electrification involving any distance must depend upon some form of overhead contact for the distribution of power to the trains, regardless of the system used. There will be, therefore, certain basic principles involved in all such installations governing the general design and application of such contact systems.

This paper is presented to the Institute, therefore, with the thought of setting forth some general methods, formulas and solutions which have been found very valuable in the mechanical design of several types of catenary construction on the 11,000-volt single-phase a-c. electrification of the New Haven system, and which may be applied to any other catenary design. The paper represents the elaboration of design notes which have been accumulated during the past fifteen years, and while containing much that may not be new, nevertheless it includes, especially in connection with the application of catenary construction to curved track, some rules and methods of design which have not, to the writer's knowledge, been set forth heretofore in a form available to engineers who may be interested in the general problem.

The details of design, including required conductivity,

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size of contact, insulation, hardware details, attachments, etc., will vary with the requirements of each installation and the ideas of the designer. Such details, while of great importance, are not included in the scope of this paper. The New Haven design details are used merely as examples to illustrate the specific applications of general methods.

"The fundamental requirements of an overhead contact system for high-speed railway electrification are:

a. It must, within prescribed limits, be parallel, or nearly so, to the track center line. When changes are necessary in the normal elevation above the track, the gradients must be such that the current collectors on the locomotives and cars will follow the contact wire without leaving it and without excessive pressure due to inertia; that is, the relative grades must not be too abrupt.

b. It must support, without great distortion, its own weight together with superimposed vertical loads due to sleet and horizontal loads due to wind.

c. It must posssess consistency in flexibility; that is, hard spots should not occur in a construction design to possess a certain amount of yielding, nor should soft spots occur in a system possessing inherent rigidity.

d. It must transmit the power supply, and afford suitable contact area with the moving collecting device on the locomotive or car, at the required speed.

e. It must possess a high degree of reliability, and ease of maintenance.

f. It must be reasonable in cost."

In that part of the paper dealing with the choice of maximum span length, and choice of messenger material and sag, all of which are of fundamental importance, no mention is made of the influence of the very heavy loadings and very high conductivity requirements of the very low-voltage systems of 3000 volts or less. It is, of course, obvious that these factors will have an important bearing on these details.

Part I of the paper deals with construction over straight or tangent track, and is in general a review of methods and formulas which are necessary as an introduction to Part II, which shows the application of catenary construction to curved track. Two general types of construction on curved track are discussed. Section A deals with tangent chord construction, and outlines span limits, proper location of the contact wire with respect to the track centerline, and the advantages of this type of construction. Section B deals at length with the theory and design of the so-called inclined catenary, and its adaptation to the track alinement.

The design of the earlier installations of this type of construction on which the spans were fairly short was based on the assumption that the shape of the trolley and messenger as projected on a horizontal plane was a parabola, and that the rods all had the same inclination. When this theory of design was later applied to longer spans, and on heavier curves, it was found that appreciable errors would result, due to the fact that the shape is not necessarily parabolic, but of some other general family of curves, of which the parabola is one special case, and the catenary curve another.

The solution of the problem set forth in this paper involves developing the actual shape of the trolley curve from the forces acting upon a given design, by determining ordinates from an axis at regular intervals corresponding to the hanger spacing. The shape factor thus determined is multiplied by another factor (called the multiplier) which is dependent on the degree of curvature, to fit the known dimensions of a given curve and span. The horizontal dimensions thus determined are then geometrically combined with the vertical dimensions of tangent catenary and the actual inclined dimensions arrived at.

In the solution of symmetrical spans on simple continuous curves, but one shape factor (called the U shape) is used. If the span is on a symmetrical reverse curve, another shape factor (called the S shape) is used. Asymmetrical spans involve the use of both shape factors to a greater or less degree. Somewhat the same general method of solution has been employed, I believe, by Mr. H. S. Richmond, on catenary construction installed by Gibbs and Hill.

Certain correction factors must be used with the multipliers to avoid noticeable departures from the track shape at the point of support. The method illustrated in Fig. 41 is, in reality, an over correction to allow for temperature variation distortion, since the exact correction would still show some distortion of the shape at temperatures other than normal.

One point not definitely mentioned in the inclined catenary application is that care must be used to locate the supporting structures about points of curvature, or points of compound curvature so that messenger offsets will be the same for the spans either side of the support. This means that, in general, the change in alinement must be near the low point of the span, although the method of design allows considerable latitude in its location.

The limitations, advantages, and disadvantages of this type of construction are set forth, and installation methods touched upon briefly.

The graphical charts shown apply in the majority only to the New Haven design, but similar charts may be made for any other design.

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The world's largest artificial lake—the water of which is to produce electric power in Alabama—will soon be formed. A dam 200 ft. high and 2000 ft. long on the Tallapoosa River, about 20 mi. from Birmingham, is backing up water for the new Lake Martin which will be 63 mi. long and impound three times as much water as is walled up by the great Muscle Shoals dam. The project cost about $20,000,000 but the demand of the South for more electric power is expected to more than justify the cost.

# Application and Design of Load Ratio-Control Equipment

BY ARTHUR PALME[1]

Member, A. I. E. E.

***Synopsis.***—*Load ratio control of transformers, which means the possibility of changing the transformation ratio without interrupting the load, has found very rapid adoption on account of its wide application possibility. It provides the long sought solution for a voltage regulation on industrial loads and large blocks of power, and enables a perfect tie-in operation of two or more power systems with any desired load dispatch regardless of voltage or power factor. It is the only economical method known to operate extended transmission systems on an equi-potential basis. The paper gives the various possible applications and some details of the electrical and mechanical design of the apparatus.*

* * * * *

## Application

THE numerous papers published during the last two or three years on transformer equipments in which voltage taps can be changed without dropping the load, dealt with the subject either in a theoretical way or they described a particular installation. A large and continuous amount of research and constructive work has been and is being done by a number of large manufacturers to improve such apparatus. Seldom before have operating engineers so quickly taken up a newly developed line of equipment. In less than three years since its conception one manufacturer alone has been able to place well over one million kilovolt-amperes of load ratio control transformers in service.

Several reasons account for this almost spontaneous adoption, the most outstanding of which is the wide variety of possible applications.

It is the purpose of this paper to enumerate these applications, to give examples of typical existing installations and to give a short account of the design of such equipments.

A change of the potential across the secondary terminals of a transformer or a voltage regulation of its secondary without disturbing the existing load is the basic foundation of all applications.

*A single-phase industrial load* with a demand for frequently changing voltage is the simplest application of load ratio control. Electric furnace work is the chief representative of this class of service. The close regulation of temperature usually demanded for resistance or arc type furnaces calls for a relatively large number of taps on the transformer winding; up to 20 voltages will not be unusual. This wide range is invariably combined with very frequent operation. Assuming three heats per 24 hr. and a gradual rise of voltage over a range of 18 steps for each with return to the lowest before the next heat, gives, for example, 108 operations per day. When it is considered that installations of this type are, as a rule, placed and operated in a permanently very dusty atmosphere, it appears obvious that only the most sturdy equipment can be expected to stand up under these conditions.

Tap switches, or as they have become known, "ratio adjusters," are at present not commonly made for more than 12 positions. With an arrangement as shown in Fig. 1, however, it is possible to make as many as 22 connections. One of the two switches $S_1$ and $S_2$ is normally closed; during a brief transient period both of them appear closed. Sufficient reactance in the winding limits the circulating current. The ratio adjusters $R\,A_1$ and $R\,A_2$ are mechanically connected by an intermittent gearing, permitting the turning of only one of them at a time.

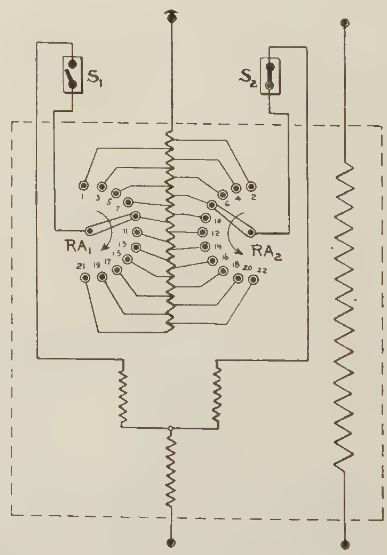


Fig. 1—Load Ratio Control Diagram for a Large Number of Taps

By providing three-phase switches and ratio adjusters, the above described equipment is applicable to a *three-phase industrial load* taken from either a three-phase transformer or a three-phase bank. Remaining within manageable limits of current and voltage will decide in each case in which winding the ratio adjusters can best be placed. In determining the cost of such equipment for different voltage limits, a great difference will be found between windings which are

1. Transformer Engg. Dept., General Electric Co., Pittsfield, Mass.

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isolated from ground and grounded *Y* transformers. Ratio adjusters and switches must be chosen for full line voltage in the former case, while on grounded windings only a fraction of the line voltage is impressed upon adjusters and switches if they are placed at the grounded end.

Except perhaps in size and capacity, no definite distinction can be made between a transformer for an

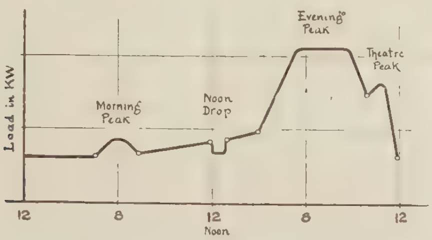


Fig. 2—Average Daily Load Curve

industrial load and a transformer in a station which provides a block of power for a wide variety of consumers. Consequently load ratio control equipments for either of these cases will be called upon to perform much the same duties. Experience has shown, however, that the frequency of operation which may be expected from the tap changing apparatus on a station transformer is rather small. An adjustment of line

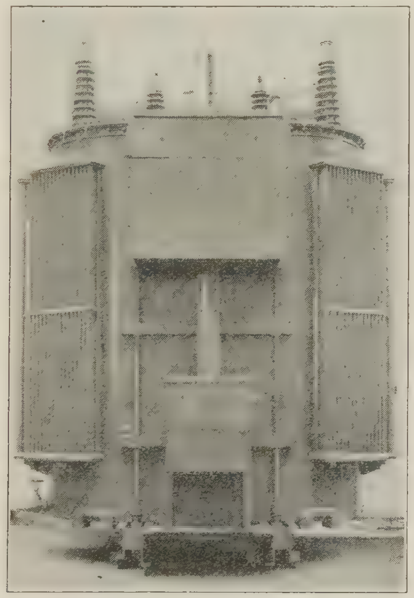

Fig. 3—Load Ratio Control Transformer, Rated H-60-8333-69300-11550

voltage is usually desirable only when the load changes considerably, as close voltage control is usually obtained with individual feeder regulators. The average daily load curve shows seven major changes. See Fig. 2.

For the transformation of large blocks of power with the high voltage not exceeding about 66 kv., the customer may choose between three-phase units or banks of three single-phase units. Installations for higher voltages as a rule are built as banks of single-phase units. Load ratio control equipments for these two types, while basically identical in performance, may differ in their execution.

It seems beyond doubt that the placing of the desired

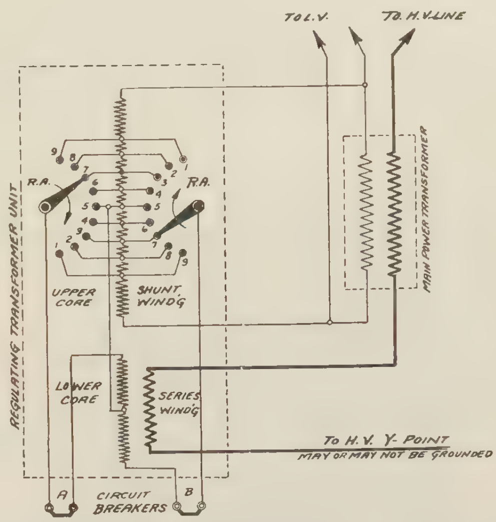


Fig. 4—Single-Phase Diagram of Load Ratio Control, Using Power Transformers With Separate Regulating Transformer

number of voltage taps on the main winding of the power transformer itself is the logical and most economic method for any three-phase transformer. The ratio adjusters and the required intermittent gear can well be located within the transformer tank, which minimizes the use of high-voltage bushings.

Not quite so obvious is the decision as to which method of load ratio control will be the most satisfactory for a bank of three single-phase transformers. According to one method, each phase may be considered as its own transformer with its load ratio control

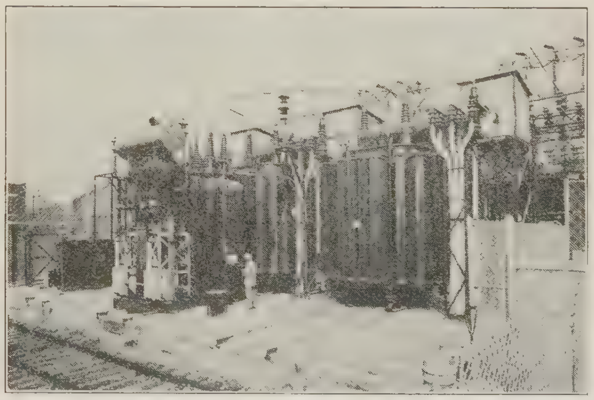

Fig. 5—Installation at Schuylkill Station of Philadelphia Electric Co., 60,000-Kv-a. Bank, With Three-Phase Regulating Transformer

apparatus, and the remote control is so arranged that all three transformers are changed simultaneously. Each transformer has the requisite number of taps, two ratio adjusters, an intermittent gearing and its external remote control operating mechanism. Fig. 3

gives an example of this type of transformer. The other method leaves the three power transformers free of all taps and calls for a separate three-phase regulating transformer which is excited from and in series with the power units. The size of this regulating unit in output kilovolt-amperes is governed by the desired range of regulation. For example, if a range of ± 10 per cent is wanted, the regulating transformer output

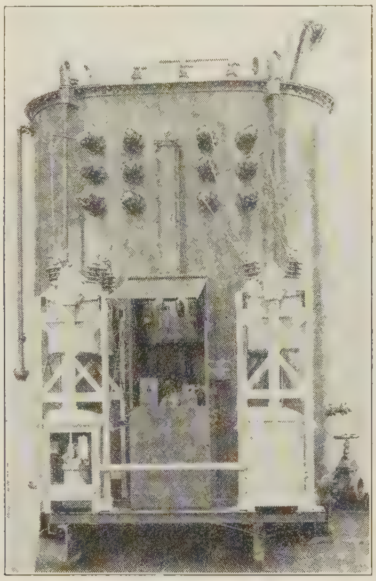

FIG. 6—LOAD RATIO CONTROL TRANSFORMER W C T-60-60,000 (667)-12,000-13,200-REGULATING UNIT

would be substantially one-tenth of the output of the regulated bank of single-phase transformers. All the voltage taps required for the regulation are placed on the three phases of the regulating unit and are connected to two three-phase sets of six ratio adjusters.

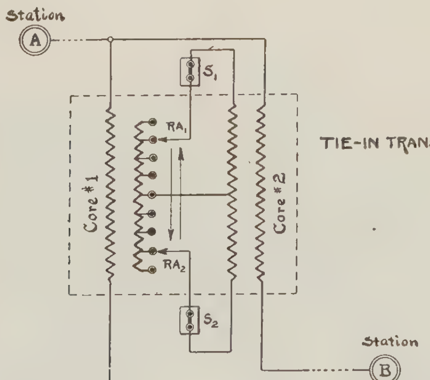


FIG. 7—DIAGRAM SHOWING CONNECTION OF TIE-IN TRANSFORMER

The two sets are turned by the intermittent gear which is actuated from one external operating mechanism.

Such an arrangement has much to recommend it. The design of the power units is greatly simplified, being standard design throughout. As only one operating mechanism is required, the control system loses much of its complexity. The switching circuit, a can be seen from Fig. 4, may be isolated from the regulated circuit, and potential as well as current can be chosen to allow the use of standardized equipment. The power units can be operated at any time without the regulating unit if demand or necessity arises. These four advantages will compensate readily for the slightly higher cost of an installation with a regulating transformer. An example of a 60,000-kv-a. bank of transformers with a separate regulating unit is shown in Fig. 5. The three self-cooled, 20,000-kv-a. units are of the radiator type, while the much smaller regulating transformer is placed in a tubular tank. Two of these banks operate at the Philadelphia Electric Company in their Schuylkill Station. A similar bank, also of 60,000-kv-a. capacity, was recently placed in service by the Commonwealth Edison Company in Chicago. The

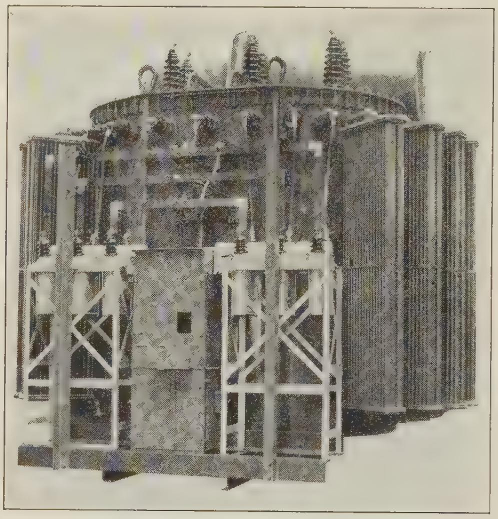

FIG. 8—EXTERNAL VIEW, LOW-VOLTAGE SIDE, H T-60-36,000 (OUTPUT) 66,000Y-59,400Y/72,600Y-D AUTO-TRANSFORMER, DUQUESNE LIGHT CO.

regulating transformer for this bank is shown in Fig. 6.

Another field of application for load ratio control is the tie-in transformer to couple two transmission systems with different and varying voltages at the tie point. The size of such a transformer will depend upon the range of ratio control and the kilovolt-amperes to be transferred from one system into the other. Fig. 7 shows the schematic connection, and Fig. 8 the appearance of a tie-in load ratio control transformer in a 36,000-kv-a. line. To fulfill its purpose of controlling the flow of reactive kilovolt-amperes in either direction, the control on such a tie-in transformer must permit a voltage reversal in the series winding which can be done readily by moving the two adjusters in Fig. 7 past each other.

Finally, a transformer with load ratio control can often compete successfully with a synchronous condenser, which is used floating at the end of a transmission line, accomplishing a dual duty, namely,

improvement of power factor and voltage regulation. If the former duty is not sufficient to warrant the cost and the losses of a synchronous condenser, voltage regulation may be performed more economically by a transformer the ratio of which can be changed while fully loaded.

## Design

Several methods are known whereby the ratio of primary and secondary voltage of a transformer may be changed without interrupting the load, among which the following three are best known:

*Progression Method.* The taps of the winding are connected to a straight row of contacts over which glides a double brush. The two halves of the moving brush are at all times tied to the ends of a reactor. While moving from one to the next contact, the reactor will momentarily take up and limit the short-circuit current of one transformer tap. The ensuing arcing, reduced to a minimum by the reactor, is not prohibitive for small capacity and quick brush motion. For larger capacities, the arcing may be diverted from the brush and the main contacts to a separate, mechanically interlocked and magnetically blown contactor. This method is used extensively on the transformers of European locomotives. It is limited, however, to an output of a few thousand kilovolt-amperes and moderate voltages.

*Multiple Switch Method.* Method 1 may be modified by connecting every tap to an external oil switch. A change from one tap to the next is then possible without losing the load if the second switch is closed an instant before the first one is opened. A common reactor limits the short-circuiting of the tap section during the short transient period when two adjacent switches are closed. If this protective reactance is designed for the purpose, or if there is sufficient inherent reactance in the transformer winding itself, twice as many operating voltages as taps may be obtained by leaving two adjacent tap switches closed. This will, of course, entail a certain amount of permanent internal circulating current. A row of mechanically operated and interlocked contactors may be found in some cases suitable for this method.

*Double Circuit Method.* If a design of ratio adjuster is available which is mechanically and electrically absolutely dependable, this method will be found most economic and versatile. The transformer is equipped with a double winding, each with the required taps and its own ratio adjusters. By means of external oil switches, one and then the other half can be "killed" for its tap change. Under normal operation both halves are in parallel. The method may be modified as per Fig. 1 or Fig. 4 where alternate or the same taps are brought to two ratio adjusters, establishing two circuits, each with an external oil switch. Using standard and highly developed oil switches, neither capacity nor voltage set any upper limits to the application of this method.

In American power transformer practise, only methods 2 and 3 have found general application. In practically all cases remote control is demanded. The definite sequence of opening and closing of switches, mentioned above, is usually obtained by remote motor control. The same motor is called upon in method 3 to turn the internal ratio adjusters, one at a time. An intermittent gear, specially designed for this purpose, enforces and interlocks the correctly timed motion of the two adjusters.

Several safety features have become standard parts of such remote-control mechanisms. Limit switches against over-running end positions, alarms for incomplete operating cycle or premature stoppage, arrangements for keeping the three single-phase units of three-phase bank in step, remote position indication and emergency hand operation, are being provided on each load ratio control equipment. For substations without attendance, automatic control can be furnished with a contact-making voltmeter as basis. To prevent, in such

Fig. 9—Bank of Two H T-60-10,000-41,400-11,000 Equipped For Automatic Load Ratic Control Furnished For Cleveland Electric Illuminating Co.

a case, a too frequent operation, a positive and adjustable time delay is included. An automatic installation of two 10,000-kv-a., three-phase transformers is shown in Fig. 9.

The mechanical and electrical parts of load ratio-control equipments are integral with their transformer, and must therefore conform to its type. For outdoor installation, circuit breakers and the operating mechanism must be made to withstand the influence of the weather. Outdoor type circuit breakers and a suitable housing over the mechanism, as shown, for example, in Fig. 6, answer this purpose. Although it does not seem fully consistent with generally accepted outdoor practise, where vast amounts of bare and alive conductors are suspended overhead, the connections between transformer and circuit breakers may readily be made inaccessible by covering them with a housing, such as shown in Fig. 9, or oil immersed, high-voltage contactors may be used instead of circuit breakers, giving an outside appearance like Fig. 3.

While the wide range of application possibilities of load ratio control was pointed out in the first section of

this paper, it is apparent from the second section that there is also a wide range of designs available to suit any particular condition. It should be mentioned, however, that the parallel circuit method, or any variation thereof, is applicable to any condition, lending itself therefore admirably to standardization and quantity production of the mechanical equipment which in turn brings about low cost and quick delivery.

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# Electricity as Applied to the Petroleum Industry

B. K. HOWARD[1]

Non-member

WITHIN the last few years rapid strides have been made toward electrification of the petroleum industry. The trend is definitely toward the use of this form of power for all purposes except heating. Motors and attendant equipment are but the first links in this chain of power supply—distribution lines, substations, transmission lines, and the central generating station must increase greatly to care for the requirements of the latest industry to swing to purchased power in the face of adequate and cheap fuel supply easily available at the point of application.

One of the petroleum companies served by the author's company requires in a single Texas oil field an average of 4200-h. p. capacity to operate its 200 motors with a combined nameplate rating of 7000-h. p. This customer uses 25,000,000 kw-hr. per year at a total cost of $350,000. They also own and maintain three 22,000/4160-volt substations with a combined capacity of 4500-kv-a., 20 miles of 4160-volt, three-phase distribution lines, and 7000-kv-a. in distribution transformers, together with necessary lighting and control equipment. It was necessary to install 3000-kv-a. capacity in synchronous condensers to correct the power factor of this field as the power factor is approximately 0.5.

When it is considered that this quantity of equipment is used to serve a single oil company in one field, the prospects for the future are amazing indeed.

The petroleum industry load is desirable to the utility because of its high annual load factor (from 75 to 95 per cent), because of its high revenue per horsepower of demand, and because of the magnitude of the operation, which makes it possible to extend a transmission line into almost any well established field.

The industry has been slow to electrify because of the abundance of natural gas in the field, and because of the easy availability of oil for internal-combustion engines. Only of late years has the utility been able to demonstrate conclusively that electric power costs are such a small percentage of the operating expense, that the advantages incident to its use far out-weigh the slight additional expense.

In all branches, shut-down time is considerably less with electric power and shut-downs mean production forever lost. Motors are uniformly more reliable than engines, but it is not here that the major saving appears. The more uniform power flow of the motor means less shock and strain to the driven equipment. Breakage and replacement are reduced when the motors supersede engines, with the expected increased production time per day.

In one specific instance in the producing branch, electrification showed an increase of 52,228 barrels of fluid from twelve wells in a period of three months. During the three months prior to electrification, twelve gas engines with 567 well-hours shut-down time produced 386,692 barrels. After electrification, twelve 15-35-h. p. motors with 321 well-hours shut-down produced 438,920 barrels—an increase of 13.5 per cent.

Shut-down time was distributed as follows:

| | Engines | Motors |
|---|---|---|
| Cups | 18 | 24 |
| Rods | 144 | 81 |
| Tubing | 117 | 105 |
| Belting | 60 | — |
| Chain drive | — | 2 |
| Sprockets | — | 8 |
| Engine | 160 | — |
| Motor | — | — |
| Motor control | — | 13 |
| Electric power | — | 57 |
| Rig and Miscellaneous | 68 | 31 |
| | 567 | 321 |

Production per well-hour—Engines—15.3 barrels
Motors —17.15 barrels

The *Tulsa Daily World* said recently:

"The wisdom of the Amerada Petroleum Corporation in equipping its 80-acre lease in the North half of the Southeast of 16-10-8, the Cromwell Field, with electric pumping equipment, was proved good during the recent blizzard. While other properties were more or less shut down because of frozen water and gas lines, the Amerada pumped right along. Only six men are kept on its lease, because the use of electricity enables a reduction in working forces."

The personal element also appears in the comparison in that the motor, being so easy to handle, will be back in operation after a shut-down in much less time than

1. Commercial Manager, Texas Power & Light Company.

*Presented at the Regional Meeting of District No. 7 of the A. I. E. E., Kansas City, Mo., March 17-18, 1927.*

the engine, which must often wait for the arrival of the day force before operation is resumed. Any oil-field operator who has attempted single-handed to start a "hot-spot" engine after it has cooled down will readily appreciate this feature.

As to power uses to which electricity is admirably adapted, the entire range of the petroleum industry is available as a field.

In production, drilling by electric power has been found desirable, due to ease of control, longer life and better service to be expected from the drilling equipment.

And again the December *Oil Weekly* says,

"The Chanslor-Canfield-Midway Oil Company has so far accomplished the setting of numerous world records in drilling its Olinda 96 to 8046 ft., and there is difficulty in finding any record for deep-well boring which this operation has not broken.

The most interesting feature of this record well, is the fact that it has been drilled entirely by electricity. Along these lines, it is interesting to note that the power cost for drilling this well to 8046 ft. is only $8173.43, a little over one dollar per foot of hole drilled.

The electrical equipment employed on this well is a duplicate of the ten similar apparatus which the company has had in constant use since 1922.

The resistance used with this controller for starting and regulating the speed of the drilling motor is so graduated that it is not necessary to 'take a run at heavy loads,' for such loads can be picked up gradually, all of which indicates longer life to all drilling equipment. The rotary table can be reduced to five revolutions per minute. The control is so arranged when drilling that resistance can be inserted in the motor rotor circuit, which provides a decided dropping speed characteristic when sudden loads are encountered, as occurs in rotary drilling."

To the two foregoing uses in which electric power excels should be added casing-head gasoline plants and electric dehydration of crude oil.

For pipe-line transportation, progress toward complete electrification has been slower. For a number of years, the industry has been using reciprocating pumps, but recently, due to the good example set by the refining departments, the centrifugal pump has gained considerable ground, and with it, the electric motor. This development has been naturally slow, since the industry as a whole was familiar with the earlier equipment, and was reluctant to abandon tried methods for the newer untried ones. However, opposition has now been considerably overcome.

Refineries have long been large users of electricity for power purposes, and are increasing their load as conditions warrant. New developments in refining processes are expected to bring with them ever widening fields for electrification.

I predict that in ten years the petroleum industry will be totally electrified in all branches except heating. Transmission lines will follow pipe lines, allowing the installation of double the number of pipe-line stations operating as boosters, thereby keeping the pressure above 300 lb. and increasing the line capacity 30 to 40 per cent, the first cost of which is $35,000 per mile.

Electricity will serve every established field, and whenever economically possible, new fields will be developed by the same means.

## Discussion

**W. G. Taylor:** With cheap fuel in the form of natural gas and crude oil so readily available in the oil fields, the oil industry has been one of the last of the large industries to turn to electric power for its various operations. That it is doing so extensively is evidence of the rapidly increasing amount of engineering study being devoted to all oil-field work by the operating departments of the oil companies themselves, assisted by the central stations and the machinery and electrical manufacturers.

That the prospects for the future are amazing, as stated by Mr. Howard, is scarcely an exaggeration. In the United States alone there are approximately 300,000 producing oil wells, with a large number of oil-gathering and pipe-line pumps, water pumps and miscellaneous power-driven machines; and there are also from 550 to 600 refineries, both small and large. Statisticians tell us that this entire industry even now is less than 5 per cent electrified. Yet one electrical manufacturer has already sold over 200,000 h. p. in motors for well pumping and drilling alone, without counting those applied to other work, and this is apparently only a small forerunner of what will follow.

Mr. Howard makes the prediction that in ten years the petroleum industry will be totally electrified in all branches except heating. Perhaps this prediction will be realized, as we all hope it will, but some factors make it seem doubtful that this millennium will be reached so soon. For instance, there are many thousands of wells in the eastern fields, (including Pennsylvania, Ohio, West Virginia, etc.), which are very small producers and which are pumped only a few hours a day, at low expense. They have been pumped so long that the investment for power equipment has been practically written off the books. Even if, by the adoption of electric drive on these wells, the running expenses could be cut to half, the money saved would probably be too little to pay for the new investment in a reasonably short time. Obviously, electric drive will not be applied to such wells until the gas supply seriously declines, and while this situation has already been reached in some places, it is doubtful if it will be universal in another ten years. Eventually, however, we may look for motors on such wells.

Drilling is often done by contractors who provide their own power equipment. Inasmuch as they must use steam engines when electric power is not available, it is difficult to induce them to duplicate their investment by purchasing electrical equipments also. This is one of the reasons why drilling is not more extensively done by electricity.

Another factor is the attitude of many of the power companies toward the drilling load. Although electric drilling leads naturally to electric pumping, the drilling load is characterized by high peaks and relatively small kilowatt-hour consumption, and is not attractive to the central station on that account. Furthermore, long line extensions are often necessary to pick up the drilling load in a new field, and the power companies can scarcely afford to make these without assurance of a steady future return on the investment. The oil companies are not usually willing to carry the burden, and by the time the new field proves to be a producing one, the opportunity to electrify the drilling rigs has passed and the oil companies have installed many gas engines for pumping because they could not wait for electric power. However, many of the power companies must be given credit for their growing interest and aggressiveness in these matters, and this is materially stimulating electrification.

**L. J. Murphy:** Mr. Howard listed a tabulation in his paper

showing the comparison of shut-downs with gas-engine drive and electric-motor drive in a certain field in Texas. In this connection I should like to say that I have similar data which show that the percentage of shut-downs with the electric drive averages 40 per cent less than the shut-downs with gas-engine drive. These shut-downs are from all causes, including engines, belts, rigs, rods, and tubing.

When a power salesman or an electrical man approaches an operator, the first question asked is, "How much is the power going to cost?" When he gives the information that, for the average well, it will run any where from $80 to $90 and for some wells as high as $295, while in other cases it will be as low as $45 a month, he is immediately told that it is too expensive with the further comment, "Why should I use electric drive when I have all the free gas I can possibly use? In fact, some of it goes up into the air and is wasted." The answer then is in behalf of maintenance and fewer shut-downs.

Mr. Howard passed lightly over the matter of labor charges. With the electric drive, I know of cases where one pumper handles as many as 33 wells, but the average number of wells per man will be in the neighborhood of 15 or 16. On the other hand, the pumpers handling gas engines are doing well if they can take care of 8, as in many cases where the engine is repeatedly giving trouble and requiring attention, one pumper to every 2 wells is quite often necessary.

Another feature is the roustabout gang. These are the fellows who do the heavy work in the field, on rods, tubing and derrick. It is to be expected that with the percentage of shut-downs of wells being reduced 40 per cent, the roustabout gang can also be reduced by a similar percentage, and actual results bear out this expectation.

On a lease where there are, say, 100 wells operating with gas-engine drive, and they have 125 roustabouts, upon changing over to electric motor drive, the number of roustabouts can be reduced to approximately 75 men. This represents a saving at $165 per month per man or $8250 per month, or $99,000 per year. It can readily be seen that this item is one that should be taken into consideration in advancing electrification.

**E. B. Freeman:** I don't believe Mr. Howard brought out one of the things that is uppermost in my mind with regard to the use of electricity in oil-field development, that is, the pumping of oil wells by means of natural gas. In the mid-continent field in Oklahoma, the Seminole oil field, (from which I hail, and which has been producing about 320,000 barrels of oil per day), is being pumped by means of electric motors on air compressors or gas compressors. This, in many cases, has increased the flow of the well 100 per cent, and, by the way, it is an excellent thing for the power companies because it is a 24-hour load running at 100 per cent load factor, or thereabouts.

I believe he did mention in his paper an article from the *Tulsa World*, telling of the Amerado Petroleum Company going through a big sleet storm without an interruption. That happened to be on our lines and they are one of our largest power consumers. They have one station that consists of twenty 75-h. p. motors and four 100-h. p. motors that has been running continuously with a shut-down of one or two motors at a time for about 60 days.

The Seminole oil field is a comparatively new field. Six months ago they struck the first well and I believe we had a load of 75 h. p. Due to the fact that we had a high-tension line in that vicinity we were able to take on considerable load and at the present time we are pumping to the pipe lines about 80 per cent of the output of that field and have connected in the one field a little more than 12,000 h. p. in the last six months, and the majority of this is motors on air compressors.

**B. K. Howard:** I probably should have been more explicit in predicting that the petroleum industry would be totally electrified in all its branches within ten years. I meant by this that all new development would be electrified where electric service was available and in some cases where the oil companies would generate their own power for electric drive.

With reference to pumping wells by means of natural gas: There has been very little of this done in Texas; however, there has been considerable development in the pumping of wells by means of compressed air in this section.

My company has recently installed twelve 75-h. p., motor-driven air compressors which are producing over 6000 barrels of oil per day. These motors replaced gas engines, and it was found upon replacing engines with motors that eight motor-driven compressors would supply the same quantity of air at the same pressure as twelve engine-driven compressors, due to the constant speed with sufficient horsepower to drive each unit.

We have just obtained figures, on pipe-line pumping covering a 30-day period, on one of the stations having installed three 200-h. p., motor-driven, reciprocating pumps, two operating and one as a spare. There were handled during the 30 -day period, 795,310 barrels of oil at 500-lb. pressure through a 10-in. pipe line, consuming 116,400 kw-hr.; and in another station, on the same line, there were handled during the same period 609,266 barrels of oil at 600 lb. pressure, using 159,100 kw-hr. pumping into a line a part of which was 8-in. and the balance consisting of two 6-in. lines, causing higher pressure due to size of line. The cost of pumping was approximately two mills per barrel for electric energy. We understand that the equivalent cost with oil-engine-driven pipe-line pumps is approximately three one-half mills, which takes into account the difference in labor and maintenance.

In conclusion, I feel that the opportunities for the development of the use of electricity in the petroleum industry have now reached the point where the operating executives of the oil companies will receive and seriously consider electricity more intensively than they have in the past, during the pioneerng of this field, and we, engaged in the electrical industry, can look forward to a very substantial amount of business from this source.

## DRONE OF AIRPLANE ILLUMINATES LANDING FIELD

No longer will it be necessary to keep airplane landing fields brilliantly lighted all night when a new invention only recently demonstrated is perfected to the point of being manufactured in quantity. The noise made by the hum of an airplane 1000 ft. in the air closed the switch that lighted a bank of flood lights at Bettis Field, McKeesport, in the first demonstration of the sound sensitive automatic lighting apparatus developed by T. Spooner, an electrical research engineer.

Merle Northrup, an air pilot, completed the experiment by bringing the plane to the ground in the glare of powerful lights turned on by the steady throb of the airplane's motors.

The device uses the drone of the airplane to control electric energy. From a tiny current at first this controlled energy is increased in power by amplifiers until it is strong enough to throw a good-sized lighting switch.

A loud-speaker operated reversely is the "ear" of the mechanism. Laid on its back it gives the apparatus a directive effect with reference to noises from above. A microphone completes the auditory section. Passing through several amplifiers the impulse then passes through the time-limit relay, the last step before the current automatically throws the lighting switch.

The switch locks automatically and the lights remain on until the switch is thrown by a field attendant.—*Tel. and Tel. Age.*

# Development of Automatic Switching Equipments in the United States and Europe

BY A. H. de GOEDE[1]

Associate, A. I. E. E.

***Synopsis.***—*This paper gives a brief outline of the history and general development of automatic switching equipments in the United States and Europe, as applied to power equipment.*

*A general review is made of the advantages of automatic equipments, consisting not only of a saving in operating expenses, but also of better operating characteristics as compared with manually controlled stations. The various designing problems, adherent thereto, are pointed out.*

*A comparison based on personal observation is made between the conditions in the United States and Europe, which accounts for the less rapid development and less extensive applications of automatic equipments in Europe, and a brief review is made of the results obtained in the latter years.*

*Mention is made of the more recent applications, such as to mercury arc rectifiers. A brief description is also given of supervisory control systems, the development of which has progressed hand in hand with the automatic equipments.*

*The accompanying illustrations show some typical modern American and European installations.*

* * * * *

## Introduction

It is interesting to note that the development of certain lines of the electrical industry shows widespread differences in the United States and Europe. The automatic switching equipments for the various classes of electric service form a striking example.

The idea to cut down the operating expenses of electric railways by the use of automatic substations, eliminating the attendants and operating only when needed, found its conception in the United States about 14 years ago. These equipments reached a high degree of reliability within a comparatively short time. After the war period, and after the initial installations had proven their worth, the automatic switching equipments found application on a large scale, not only for electric railways but for practically all kinds of service. In Europe, however, the first trial installations were not made until 1921-1922, and they had not been taken into commercial use on any appreciable scale until about 1924. The tardiness of Europe in using automatic equipments may be explained by the difference in economic and operating conditions as compared with the United States.

## Development in the United States

It was only natural that the high cost of labor in the United States should create a demand for unattended stations. The first installation of this kind was tried out in Detroit in 1912 where a synchronous converter for lighting service was remotely controlled from a substation a mile away. The success of this arrangement directed the attention of electric interurban railways to it in an effort to reduce their operating expenses. Owing to the greater distances between substations, as in the case of interurban lines, the remote-control scheme was less suitable and the development of full automatic substations had to be taken in hand. Automatic stations should be designed in such a way that they perform the following duties, which are ordinarily taken care of by an operator in a manually controlled station:

1. Start the machine on load demand,
2. Protect the machine during the starting period,
3. Connect the machine to the system,
4. Protect the machine, when running, and control its output,
5. Take the machine out of service when there is no further demand for it.

How well the early designers of these equipments realized the various problems associated with their functioning is proved by the fact that the first installations of 1914 are still in service.

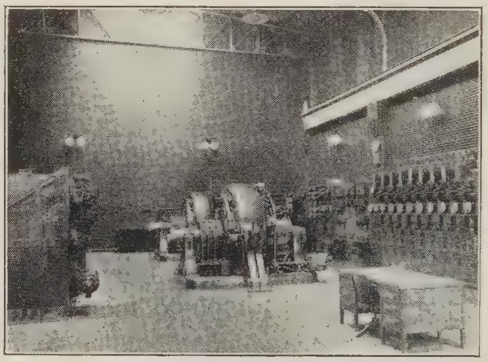

Fig. 1—Automatic Switching Equipment for Two 2000-Kw., 600-Volt, D-c., Synchronous Converters for Railway Service, with Feeders, Combined with Distributor Supervisory Control. (Oak Square Substation of Boston Elevated Railway, Brighton, Mass.)

The success of the very first automatic switching equipments for interurban and city railway service was so striking that a demand developed soon for their application to other fields. After a temporary slackening during the actual war period, this demand became more urgent around 1920, and since that time they have been used extensively for all kinds of electric service, of which may be enumerated their widespread applica-

1. Automatic Switchboard Dept., General Electric Co., Schenectady, N. Y.

*Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Pittsfield, Mass., May 25-28, 1927.*

tion to railway, hydroelectric, lighting, mining and industrial (in particular, steel mill) service.

Hand in hand with the development of automatic control equipments for machines came the design of automatic reclosing a-c. and d-c. feeders in order to derive the maximum benefit from these installations. By selecting the most appropriate machine and feeder control equipments, a most flexible installation can be secured.

The experience obtained with the first installations

Fig. 2—Automatic Switching Equipment for Two 4600-Volt, A-c., 3000-Kv-a., Waterwheel Driven Generators. (Interior Sugar Island Station, St. Lawrence Valley Power Corporation, Potsdam, N. Y.)

showed that the anticipated saving in operating expenses materialized. The main item was the saving in wages for two or three shifts of substation operators, against which stood a surprisingly small amount for periodic inspection. An appreciable item was also the reduction in power consumption, as the stations are only in operation when there exists a load demand on the system, thus saving the running light losses over considerable periods, especially in the case of interurban lines with infrequent service. Further savings resulted due to the fact that it was now economically possible to install a larger number of small substations throughout a certain territory instead of a few large substations. Not only did this give improvement of service owing to the better holding of constant voltage on the entire system but also a considerable saving in feeder copper was obtained which compensated to a certain extent for the higher initial cost of the automatic substation.

It was soon discovered that not only a saving in operating expenses could be obtained by means of automatic stations but that these equipments had also many other important advantages. In order to secure proper operation, it is essential that an automatic station be provided with a complete set of the well-known protective features which should be designed and arranged in such a way that a certain predetermined function will take place for any anticipated emergency to prevent damage to the machines or attendant equipment. The ordinary manual station has only a few protective devices and depends for the rest on the experience and minute observation of the operator who will never be able, in case a certain trouble develops, to take such immediate positive action as a relay especially installed to perform a definite function in case of just that kind of trouble. All operations in an automatic station occur in a certain predetermined sequence, and each step in the sequence depends upon the proper completion of the previous one, so that faulty operation is excluded under all conditions. This will allow more reliable functioning than when the uncertain human element is present.

In this respect it will be clear that the success of automatic switching equipments depends upon the correct functioning of each individual device. This has been realized by the designers of these equipments since the beginning, and every endeavor has been made to make the devices as perfect as possible. A device must be not only electrically and mechanically strong but in many cases it is also essential that it be quite sensitive at the same time, which offers some unique problems. Furthermore, these devices should operate satisfactorily over a wide range of temperature, as automatic stations are not heated. Special devices have been designed as protective, checking, regulating and sequence relays especially for this kind of service, with due regard to their probable number of operations and duration of life. While in the beginning of automatic station operation there were a few cases of device

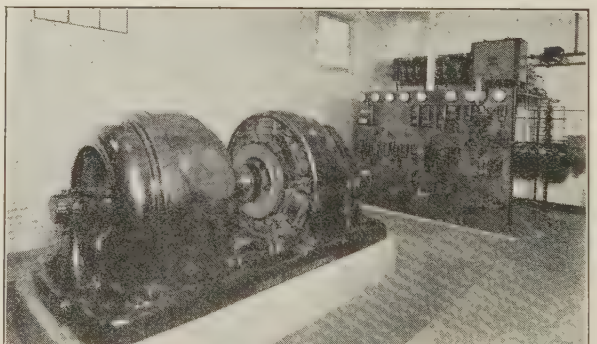

Fig. 3—Typical American Automatic Control Equipment for 275-Volt D-c., 300-Kw. Synchronous Motor Generator Set for Industrial Use

failures, the art has progressed so rapidly that a very high degree of reliability has been reached and device failures rarely happen.

In this way a very high class of regulating equipment has been developed for use in automatic stations, which will allow these stations to operate temporarily at a much higher overload than would be considered safe in case of manual operation. The automatic protective relays will determine exactly when the load has to be reduced in order to prevent damage to the machine and will function to accomplish this. Usually, a d-c. machine will then be adjusted so as to deliver power

up to its limit, to the system at a reduced voltage. As soon as the excessive load demand ceases, the voltage will be brought back to normal. In this respect the load limiting resistors in the circuit of synchronous converters may be mentioned, as well as rheostatic and counter-electromotive force control of the shunt fields of d-c. generators. These arrangements make it possible for an automatic station to deliver power up to the very limit of the machine so that service will be maintained as far as possible.

A further advantage accruing to the use of automatic switching equipments is the fact that smaller buildings of less elaborate design can be used to accommodate these equipments as no sanitary measures have to be taken for the attendant personnel as in manual stations. This makes it also possible to locate substation apparatus in places which would not be considered suitable for manual stations. For example, if the load on an Edison lighting system in the business district of a city increases to such an extent that a new substation becomes necessary, this may be located in the load center and installed in a basement, while in many cases with manual operation a more expensive site would have to be purchased, or the substation would have to be located at some distance from the load center, necessitating expensive cable runs. Another example is formed by the installation of substations with rotating apparatus in residential districts, to which many objections usually are voiced on account of the noise. When using automatic control, it is possible to use an entirely enclosed soundproof building. It will be clear that such "noiseless" substations are only feasible with unattended equipments.

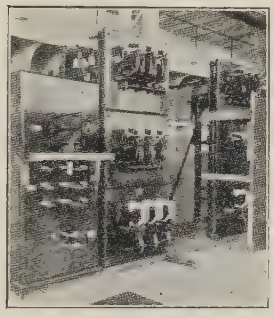


Fig. 4—Two Views of Automatic Switchboard to Control a 500-Kw., 600-Volt D-c. Synchronous Converter at Sevres Substation of the "Societe des Transports en Commun de la Region Parisienne" at Paris, Showing the Extensive Use of American-Made Devices (Reproduced from *Le Genie Civil* of December 12, 1925)

The automatic switching equipments have also made possible the profitable development of small water power sites. It has been found in many instances that the building of small hydroelectric plants with automatic control, was entirely feasible, while their development with manual control was not economically warranted, owing to excessive operating expenses. In some special cases it has been found that the building of several small plants along a river was cheaper than the development of a single high head plant of large capacity, due to the characteristics of the river-bed.

Summarizing the above, some of the most outstanding advantages of automatic switching equipments are the following:

1. No operators required,
    a. Saving in operating expenses,
    b. Freedom from labor trouble,
2. Stations operate only as needed,
    a. Saving in power,
    b. Less wear on apparatus,
3. Continuity of service and better regulation,
4. Reliability,
5. Constant protection with positive action,
6. Possibility of selecting the most economic location for a station,
    a. Saving in feeder copper,
    b. Less expensive sites,
7. Possibility of developing small water power sites.

It is not surprising that because of these paramount advantages of automatic switching equipment, their use has increased rapidly on a progressive scale. While in earlier years automatic equipments were only installed to reduce the operating expenses, it is a notable fact that during the last few years their use is considered in many instances solely based upon their more reliable service accomplishments as compared with manual control. They find more and more application in cases where continuity of service is of the utmost importance, such as in steel mills.

## Development in Europe

While the development of automatic switching equipment went ahead with rapid strides in the United States, very little work was done in this line in Europe. During the war period the capital and men were lacking for experiments and investigations which were not directly useful for the progress of the war, so that the development in the electrical industry in general was virtually at a standstill. The principal work consisted of maintaining existing installations in operating condition, while extensions were practically impossible. At the end of the war the load on several systems had increased to such a value that they were operating without any reserve at all.

After the war the demand for electric service increased greatly and the available capital was applied to the extension of the systems. As this had to be done in as short a time as possible to satisfy the demand, and as the industry was still quite disorganized, it is apparent that the time was not very appropriate to try out radical changes in design, and only the more conventional equipments were installed.

Owing to cheaper labor in Europe and the less extensive use of interurban electric railways, the demand for automatic or unattended switching stations was less pronounced. The tremendous success of automatic installations in the United States, however, directed

the attention of European manufacturers to this class of equipment, and the subject was given serious consideration, especially as the post-war depression necessitated the application of the most economical apparatus. In the years 1921-1922 several trial installations were built, practically all for synchronous converters for

Fig. 5—Automatic Switching Equipment for 1000-Kw., 600-Volt D-c. Mercury Arc Rectifier, Consisting of Two 6-Anode Tanks, for Railway Service, with Feeders, Combined with Selector Supervisory Control. (Chicago, North Shore & Milwaukee Railroad Co.)

railway service. Two distinct designs can be noticed:

1. Those which were developed by European companies with American connections, and which followed largely the American design, sometimes to the extent of using several devices built in the United States,

2. Those which were developed independently.

Even these latter equipments base their design upon the operating experience obtained in the American stations during several years. The only basic difference is that in many cases the synchronous converter is not self starting, which has never found great favor on the continent owing to the disturbances caused in the a-c. system, frequently of a small capacity. Instead, a special small starting motor is installed on one end of the converter shaft to bring the machine up to synchronous speed before connecting it to the a-c. system.

While it is the universal practise in the United States to raise the brushes from the commutator during the starting period, a few European manufacturers do not follow this procedure. It is claimed that excessive sparking on starting is eliminated by means of a special design of the commutating poles and of the field windings, so that there is no necessity for raising the brushes.

To insure correct polarity on starting, the converter field may be either separately excited or the polarity may be checked and, if necessary, automatically corrected by means of a polarized relay with permanent magnets. Both methods have found extensive use in the United States, and similarly both methods are being followed in European design. The only difference is that in American practise a special single-phase motor-generator set is used for separate excitation (field flashing), while it is the universal practise in Europe to mount an exciter on the converter shaft for this purpose.

After these trial installations had given a good account of themselves, the automatic control equipments for synchronous converters have found commercial application in the last three or four years, when their advantages became more fully appreciated. In the same manner as in the United States, they have been applied not only in order to secure operating economies but have also been used in cases where manual control was less suitable. In this regard mention may be made of a substation, Soho Square Substation of the Charing Cross Electricity Supply Commission, which is installed in the basement of a building in a thickly populated section of London. Incidentally, it may be noted that this substation will ultimately contain five 300-kw. synchronous converters for 210-volt, d-c. lighting service, which are arranged to start and stop automatically in a definite sequence depending upon load conditions of the d-c. system which is a large number of units compared with the usual station in the United States. This shows that faith exists in the reliability of these equipments. Nevertheless, automatic synchronous converter substations have found application only on a very limited scale in Europe when compared with their extensive use in the United States. The value of the load limiting resistors in the machine circuit does not seem to have been generally appreciated in Europe in the beginning. For railway work there have been installed equipments both with and without these resistors. This may be due to less rigid requirements for continuity of service, but still it can be noted that the most recent European installations make more general use of this method of load limiting.

Fig. 6—Typical European Automatic Switchboard to Control four 300-Kw., 210-Volt, D-c. Synchronous Converters at Soho Square Substation of the Charing Cross Electricity Supply Commission at London. (Reproduced from the *Metropolitan-Vickers Gazette*, of December, 1926)

## Mercury Arc Rectifiers

At this point attention may be called to the steel enclosed mercury arc power rectifier. Being an American invention, it is remarkable that its development originally progressed even more rapidly in Europe than in the United States. Above a certain definite d-c. output voltage, this apparatus has a very decided attraction as the means of converting alternating current to direct current with the highest efficiency of any known conversion method.

These rectifiers have found widespread application in Europe during the last 8 or 10 years, and after proving their reliability, the step to make them automatically controlled was soon taken. Fundamentally, the automatic switching equipment for a rectifier is simpler than for a synchronous converter as no synchronizing with the a-c. system and no polarity check is necessary. Consequently, automatic control equipments for mercury arc rectifiers have found more general application and on a larger scale in Europe than the equipments for synchronous converters. Only in the last two years a comparatively small number of mercury arc rectifiers has been equipped with full automatic control equipments in the United States. Their application gives some complications which are not known in Europe, especially due to the fact that they are subjected to extreme changes in temperature in many sections of the United States, which may effect the correct operation of the rectifier. Automatic temperature control is therefore necessary, which is not required for European installations. For full automatic equipments the American practise requires also automatic vacuum control, which is not generally furnished with the European equipments. These complications have held back the application of automatic control equipments to mercury arc rectifiers a good deal, but still their use is gradually increasing.

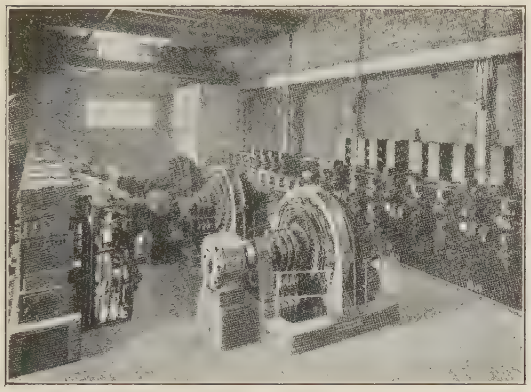

Fig. 7—Typical European Installation of Automatic Switching Equipment for Three 1500-Kw., 600-Volt D-c. Synchronous Converters at Balham Substation of the London Underground Railway, Remotely Controlled. (Reproduced from the *Metropolitan-Vickers Gazette* of November, 1926)

## Supervisory Control Systems

The development in the United States has long been concentrated on full automatic operation without any attendance whatsoever, except periodic inspection. In more recent years there seems to be a tendency to go back, not exactly to remote control, but rather to remote supervision. In this case the automatic station is allowed to function automatically by its own devices, but a dispatcher at a central point receives indications of the main switching functions, so that he is at all times fully informed by means of a system of lamps as to what happens in the remote automatic stations. Generally, the dispatcher has control of certain functions, so that he can start or stop a machine or open a feeder at will, regardless of the conditions on the system of which the substation forms a part. This feature is useful in certain emergencies. These supervisory systems have passed the experimental stage and have also reached a high degree of reliability. They allow the control and indication of a large number of separate functions over three or four common line wires, which under certain circumstances may also be used for telephony. The systems operate with a short time delay, which is only 5 or 10 sec. Simpler schemes rely on audible indication and are useful for systems where only a few functions have to be performed. These supervisory systems are based upon the use of devices which have proven their reliability in train signal, telegraph and automatic telephone service, of course with the necessary modifications for power work. A further refinement of these methods of supervision is the remote metering. Several workable schemes have been developed to transmit various meter readings automatically over large distances from a remote automatic station to a dispatcher. While this supervisory equipment is fairly expensive, many operating companies consider it of the utmost importance, because the dispatcher is constantly informed about the actions of the automatic stations, which will explain why these

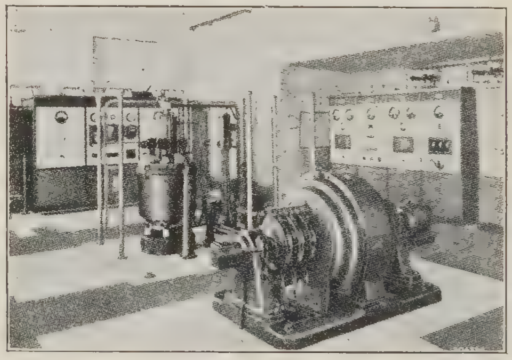

Fig. 8—Typical European Installation of Automatic Switching Equipment for 300-Kw., 800-Volt D-c. Synchronous Converter and 300-Kw., 800-Volt D-c. Mercury Arc Rectifier at St. Legier, Switzerland. (Reproduced from the *Brown Boverie Review*, August 1926)

systems have found a widespread application in the United States during the last few years.

As automatic stations have not yet been in such extensive use in Europe, there has been very little demand for these supervisory systems. A few have been developed, based mainly on automatic telephone devices.

### Conclusion

The leading manufacturers in the United States are at present prepared to furnish reliable automatic switching equipments suitable to meet all possible control operations for both a-c. and d-c. machines and for switching operations on a-c. and d-c. networks, in short, for all classes of electric service, with the only exception of generating stations driven by prime movers other than water wheels.

The application of automatic switching equipments in Europe has been on a much smaller scale and covers a smaller scope of work. Practically all installations are for railway and lighting service, with some isolated cases for the other classes of electric service.

Automatic switching equipments for practically every conceivable operating condition have been installed the world over and prove daily their paramount advantages. Their future is assured.

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# Transformer Tap Changing Under Load

BY L. H. HILL[1]

Associate, A. I. E. E.

***Synopsis.***—*Changing the voltage ratio of transformers under load is now a recognized and established procedure. Methods of changing taps under load are discussed, illustrated and compared. Equipment for obtaining smooth curve voltage control is discussed, as well as combination voltage and phase-angle control.*

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### Introduction

THE development of reliable equipment for changing the voltage ratio of transformers without disconnecting the load has, in effect, created a new type of apparatus ranking with the induction regulator or synchronous condenser in importance.

Transformers provided with equipment for tap changing under load, however, do not labor under the inherent disadvantages incident to the use of the other two kinds of apparatus. The rapid growth in popularity of this equipment has been due to the fact that for certain applications, a simpler, more compact, more reliable, sturdier, more effective, and cheaper piece of apparatus can be obtained by this than with the older forms of equipment.

The application of transformers provided with equipment for changing taps under load is very wide. Perhaps one of the most important is in connection with transformers used to tie together two large systems or parts of systems. Of next importance are units used for bulk voltage regulation of a secondary bus or to compensate for voltage drop in transmission circuits. Other interesting applications are those involved in the variation of voltage applied to rotary converters and furnace transformers.

### Methods of Tap Changing

There have been numerous methods devised and, at least to a limited extent, used to change the voltage ratio of transformers under load. These may be divided into two classes—those changing the ratio in steps and those changing the ratio along a smooth curve.

### Changing the Voltage Ratio in Steps

The majority of schemes proposed and used for changing the voltage ratio under load change the ratio in steps. Roughly, these may be divided into two general classes,—(1) those using duplicate paralleled windings in the transformer, each normally carrying one-half of the load, but adapted for carrying the entire load during the time that the taps on the other are being changed; and (2), those using a single winding with a preventive resistance, reactance, or auto-transformer across the taps involved in the transition.

### The Parallel Winding Method

Fig. 1 indicates schematically a winding arranged to change taps under load by means of the parallel winding method.

Each of the parallel circuits contains a tap changer or ratio adjuster, usually located inside the transformer tank, and a circuit breaker, which is outside of the transformer tank.

When taps are changed, one of the paralleled circuits is opened by means of the circuit breaker in its respective section and the taps are changed while the winding carries no load. During this period the entire load is carried by the other winding. When the first circuit breaker closes, the two sections of the windings are paralleled with unequal taps and a circulating current exists. This is for a short time only, as the second breaker opens immediately, permitting the taps to be changed at no-load on the second winding, while

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the first carries the total load. After this, the tap changing operation is completed by closing the breaker on the second winding with the result that the two paralleled sections again operate on equal taps.

During the interval of tap changing, one of the paralleled windings carries double normal current. The

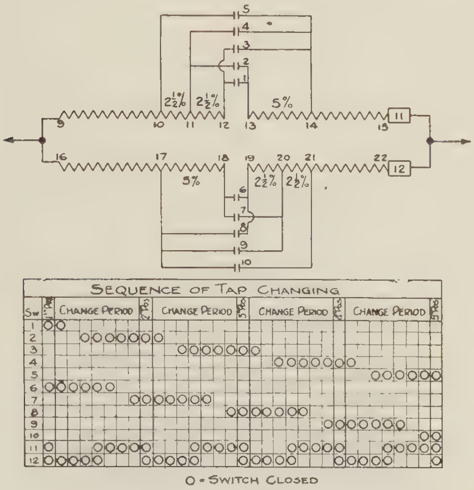



Fig. 1—Schematic Diagram and Sequence Chart of Switch Operations for the Parallel Winding Method

windings are ordinarily designed with sufficient capacity to carry this abnormal current during the tap changing operation and differential protection between windings is provided to guard against accidental overloading for a longer period of time.

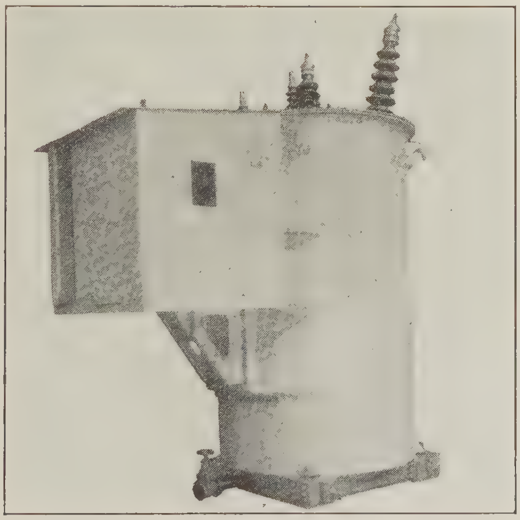


Fig. 2—20,000-Kv-a., 66,000-Volt, 60-Cycle Transformers using Parallel Winding Method

A transformer designed to change taps under load by means of the parallel winding method is illustrated in Fig. 2.

## Single Winding Method

The other methods used in addition to the parallel winding method fall into the class which uses a single winding in the transformer with a preventive coil or some other device to limit the current during the transition period from one tap to the next.

Probably the oldest form of equipment for tap changing under load employed the Stillwell regulator principle, which uses a preventive resistance temporarily bridged across taps to limit the current during the transition period.

Equipments have also been made, to a limited extent, using a preventive reactance in the circuits instead of the resistance used with the original Stillwell scheme.

A much simpler scheme than either of these two consists of using a preventive auto-transformer with a mid-point tap, as schematically shown in Fig. 3. A great many units have been built employing this method.

To obtain the full winding of the transformer in the circuit, switches 1 and 6 are closed. The circuit is then through the full transformer winding and divides through the preventive auto-transformer, one-half being through one side of the auto-transformer and one-

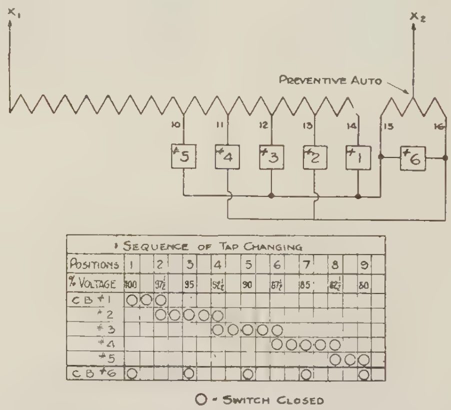



Fig. 3—Schematic Diagram and Sequence Chart of Preventive Auto-Transformer Method

half being through the other half in the opposite direction. The voltage of the transformer is therefore the voltage induced in the entire winding. To change taps, switch 6 is opened and 2 is closed. This connects the auto-transformer across the two taps and, since the line lead is attached to the center of the preventive auto-transformer, the line voltage becomes the same as it would have been had the line lead been attached to a tap midway between the two actually brought out.

Similarly, to change taps still further, the process is repeated in this manner, (Fig. 3).

In the earlier installations built using this method, the switches and preventive auto-transformers were all mounted separately and apart from the main transformer tank. In later equipments, since the preventive auto-transformer has no moving parts and can be made entirely reliable, it is mounted inside the main tank and supported from the main transformer.

Fig. 4 illustrates an installation of transformers using this type of apparatus. The tap changing equipment is contained in the sheet iron house next to the transformer tank.

The tap leads are all brought through the side of the

transformer tank, and are connected to the circuit breakers mounted in the upper portion of the stele house.

The circuit breakers are mechanically connected to the operating mechanism on the floor below.

For a short time during the transition period, one-half of the auto-transformer winding carries all of the load current of the transformer, while the other half of the winding is open. The load current is then the magnetizing current, and the voltage across the preventive auto-transformer tends to rise somewhat above normal. To limit this voltage to a low value, the design of the auto-transformer is such that the core becomes saturated when the voltage reaches a value slightly above normal.

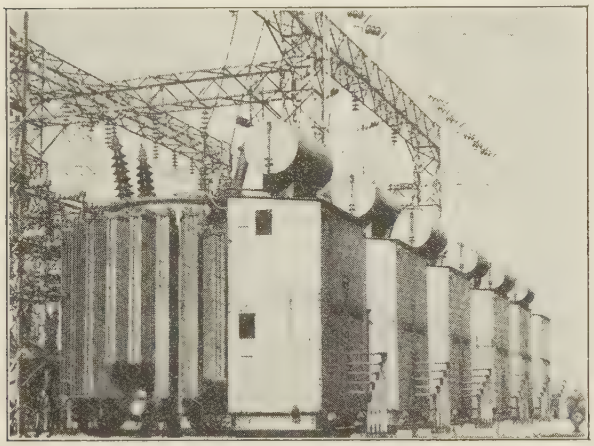
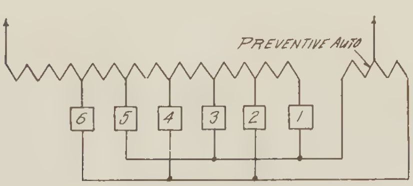


Fig. 4—Installation of 6- 10-, 500-Kv-a., 66,000-Volt, 25-Cycle Transformers using Preventive Auto-Transformer Method

In changing from one voltage to another, two operations are required; namely, the opening of one circuit breaker and the closing of another. Since the circuit breakers are operated mechanically by means of cams on a drive shaft, the correct sequence of operation is assured at all times.




| | SEQUENCE OF TAP CHANGING | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Positions | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| SW 1 | o | o | | | | | | | | | |
| 2 | | o | o | o | | | | | | | |
| 3 | | | | o | o | o | | | | | |
| 4 | | | | | | o | o | o | | | |
| 5 | | | | | | | | o | o | o | |
| 6 | | | | | | | | | | o | o |

o SWITCH CLOSED

Fig. 5—Schematic Diagram and Sequence Chart of Single-Winding Method using the Simplified Preventive Auto-Transformer

### Simplified Preventive Auto-Transformer Method

The preventive auto-transformer method, using a short-circuiting switch across the auto-transformer, has recently been simplified still further by merely the elimination of the short-circuiting switch and the use of an auto-transformer designed to carry the transformer full load current in either half of the winding with the other end disconnected.

Fig. 5 illustrates schematically the winding arrangement when this method is used. To obtain the entire transformer winding in the circuit, switch 1 is closed and the current passes through the transformer winding and one-half of the preventive auto-transformer. This gives a small impedance drop through the auto-transformer which is in series with the transformer. Since the drop is almost entirely reactive, its effect on regulation is practically negligible at power factors above 65 per cent.

To change taps one step, switch 2 is closed, placing the auto-transformer across the two taps, and giving a voltage on the mid-tap of the auto-transformer midway between the two actual tap voltages.

To change taps another step, switch 1 is opened and the conditions become as before, with the other half of the auto-transformer carrying the full current of the transformer.

To change taps still further, the process is continued in the same manner, as may be followed in detail from the sequence chart, Fig. 5.

It may be seen that, by this development, the process of tap changing has apparently reached its utmost simplicity for step-type tap changers with one switch operation to change taps, and in every other tap change, the switch closing instead of opening.

When full load current is passed through one-half of the auto-transformer with the other half open, the full-load current of the main transformer as in the case of the other auto-transformer method becomes the exciting current of the auto-transformer. Under this condition, there are no neutralizing ampere-turns from the other half, so that the transformer becomes a reactor. Air-gaps are provided in the core to give low impedance when operating in this manner which, of course, makes the exciting current, when operating as an auto-transformer across taps, higher than ordinary.

### Switches for Tap Changing Service

Circuit-breaker devices for tap changing service have entirely different conditions to meet than the ordinary circuit breaker. The ordinary breaker is designed for relatively infrequent operations with a few operations interrupting many times normal current at line voltage.

The switch for tap changing duty, on the other hand, is called upon to merely transfer current from one circuit to another, and, while it must be insulated for the service voltage, it opens but a small fraction of line voltage and usually not more than twice normal

line current. Instead of calling for a few operations with high interrupting capacity, it must be able to stand a great number of operations without losing its adjustment but with very low interrupting capacity required.

A switch for tap changing service is never called upon to interrupt a short circuit except in the remote possibility of short circuit on the system occurring during a tap changing operation. Even in this case the voltage to be interrupted would be very low but the current would, of course, be considerably higher than normal.

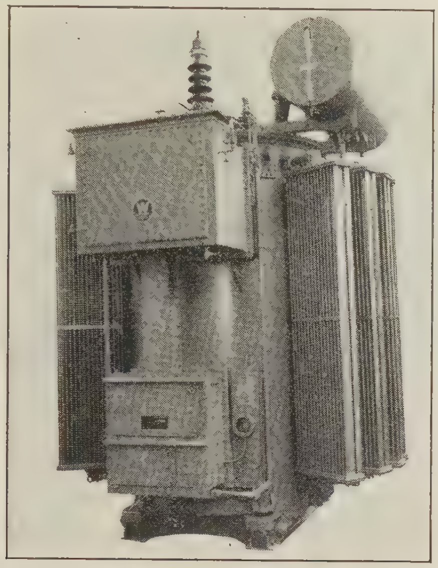


Fig. 6—12,000-Kv-a., 132,000-Volt Transformer using the Simplified Preventive Auto Method

In fact, the service required of a switch for tap changing service, approaches that of a heavy duty contactor switch. Fig. 6 illustrates a transformer provided with equipment for tap changing under load, using a specially designed switch to meet these requirements, a very simple, compact, and sturdy mechanism. The single winding method, using the simplified preventive autotransformer, was employed.

All mechanical equipment is isolated from the main transformer tank. The switches are contained in a separate oil-filled compartment on the side of the transformer case and the operating mechanism is contained in the housing below with a connecting tube enclosing the drive shaft which enters the upper compartment through an oil tight stuffing box in the bottom.

The general construction of the switch itself may be seen in Fig. 7. Condenser bushings through the side of the transformer tank support the stationary and movable contacts which are arranged to give the rolling action common with heavy-duty contactor switches. The rolling action is such that the arcing is taken at the tips so that the current carrying parts always remain in good condition. Opening and closing is definitely fixed in the proper sequence by the mechanical operation of the cams as in the case of the equipment using circuit breakers. The toggle mechanism assures quick opening, but in case of sticking or contact weld, the cams force the opening.

### Control of Tap Changing Equipments

Tap changing equipments are normally arranged for remote electrical control by the operator, with auxiliary arrangements for manual operation in case of failure of motor or control voltage.

The electrical control is such that after the operator has initiated a tap change, auxiliary mechanically operated switches on the equipment assure the completion of the tap changing operation irrespective of the action of the operator. Remote electrically operated position indicators of the dial type or of the indicating lamp type are generally used.

Tap changing equipments may also be built to operate under automatic control. The transformer illustrated in Fig. 6 was arranged to automatically control the voltage at a given point within predetermined limits.

The automatic control is initiated by a rise or fall in the low-voltage potential acting through a long time delay relay.

The use of automatic control with step type tap changers places unusual responsibility on the reliability of the apparatus. On account of the greater number of operations likely to be obtained with equipment responsive to the action of fluctuating line voltages, the time delay relay must be introduced to eliminate unnecessary operations—also to prevent the possibility of the tap

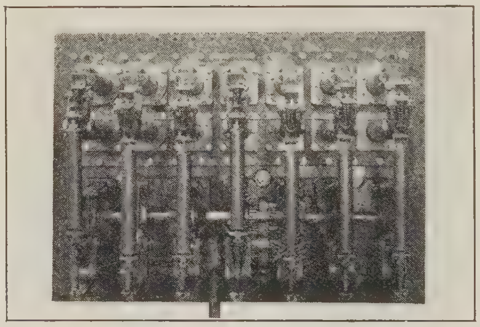


Fig. 7—Special Switch Designed for Tap Changer Service

changer operating during short circuits. Since a short circuit on the system tends to reduce the voltage, there would be a tendency for the tap changer to operate during the short circuit to raise the voltage, which in itself would be undesirable.

With automatic control of step type equipment it is necessary also to design the control equipment to free the motor-actuating circuits from the voltage-responsive circuits as soon as the motor-actuating circuits have become energized.

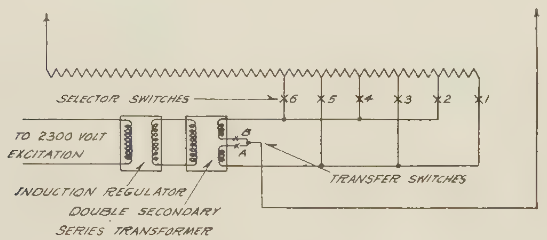
When transformers are operated as single-phase units in a bank with individual tap changing mechanisms or when two banks are operated in parallel, it is essential that out-of-step operation be guarded against. In all such cases, the automatic equipment is locked out of service and an alarm sounded.

## Comparison of Step Type Tap Changing Methods

Satisfactory tap changing equipments have been built using the two fundamental methods of step-type tap changing. There are certain inherent advantages, however, pertaining to each.

The single winding method requires fewer taps in the transformer for a given number of operating positions and gives a simpler transformer winding than the other method. On account of the less number of taps it is easier also to bring all operating parts outside of the transformer tank when this method is used. In addition, the fewer number of switch operations give the preventive auto method a decided advantage.

With the parallel winding method, however, when a wide range of taps in small steps is desired, a more compact equipment may usually be obtained by the use of the tap changer inside the main tank. This is




| SEQUENCE OF OPERATION | | | | | | |
|---|---|---|---|---|---|---|
| SWITCHES | POSITION 1 | 2 | 3 | 4 | 5 | 6 |
| A | + | | + | | + | |
| B | | + | | + | | + |
| 1 | + | | | | | |
| 2 | | + | | | | |
| 3 | | | + | | | |
| 4 | | | | + | | |
| 5 | | | | | + | |
| 6 | | | | | | + |

Fig. 8—Schematic Diagram and Sequence Chart for Step Induction Regulator Equipment

particularly advantageous with small three-phase units where space limitations make it difficult to mount all equipments outside the main tank.

## Equipment for Changing Transformer Voltage Ratio in Smooth Transition

An interesting modification of the simplified preventive auto-transformer scheme of tap changing is obtained if the two halves of the preventive auto-transformer are replaced by the two sections of a series transformer—in combination with a small induction regulator.

Such a combination is called a step induction regulator and has been used principally for bus regulation and to apply variable voltage in a smooth curve to furnace transformers, testing transformers, and synchronous converters. It has been applied also to transformers used for interconnecting two systems. Referring to Fig. 8, the switches 1, 2, 3, 4 and 5 are called selector switches while *A* and *B* are called transfer switches. The induction regulator may be a standard feeder regulator with the addition of slip-rings to make the rotor suitable for continuous rotation.

Rotation of the induction regulator rotor through 180 deg. changes the voltage in its winding from a maximum in one direction to a maximum in the other direction. In the application to step induction equipment, the voltage of the regulator is added to or subtracted from a transformer tap to provide means for transferring from one tap position to the next and incidentally obtaining an infinite number of operating positions in between.

Referring to Fig. 8, if the entire voltage of the transformer winding is desired, selector switch 1 and transfer switch *A* would be closed with the regulator rotor in the position of zero buck and boost.

To reduce the effective transformer coil voltage, the regulator is rotated to increase the voltage. At the position of maximum regulator voltage, the series transformer is designed so that the voltage of each half of the series winding is exactly the same as one-half the tap voltage.

At this point, switches 2 and *B* may be closed, since the half of the series winding connected to switch 1 reduces the effective coil voltage the same amount that the half connected to 2 adds to the voltage up to that point. Since the potential at the two points are the same, they may be connected. Continued rotation of the mechanism opens switches *A* and 1 and the voltage of the series transformer adds to the coil voltage of switch 2. As the regulator is rotated further, the voltage of the series transformer half decreases to zero when the line voltage becomes equal to the coil voltage up to tap 2. Continued rotation repeats the process to the next tap, as may be followed in detail from the sequence chart of switch operations Fig. 8.

Any of the infinite positions of the induction regulator become operating positions so that an infinite number of steps in voltage may be obtained between the extreme tap position.

It would be possible to eliminate the series transformer with this equipment, by building a special regulator with two sets of secondary coils. The use of the series transformer is desirable, however, not only because it eliminates the necessity of making a special regulator winding, but it isolates the induction regulator from the transformer circuits. The use of the relatively weaker induction regulator, therefore, does not reduce the inherent mechanical and electrical reliability of the main transformer.

When the range of voltage regulation is exceptionally large, it is economical to modify the above scheme by switching the induction regulator along an auxiliary winding, which, in turn, is switched along the main winding at less frequent intervals. The taps are changed on the auxiliary winding in the same manner as described above and the voltage of the auxiliary winding either added to or subtracted from the taps of the main winding.

Assuming that the voltage is to be increased, one of the auxiliary windings is connected to a tap such as tap 1 of the transformer, and the induction regulator switched along the auxiliary winding until the voltage of the double secondary windings is added to the auxiliary winding. The voltage added to tap 1 is then the same as the voltage of the winding between taps 1 and 2

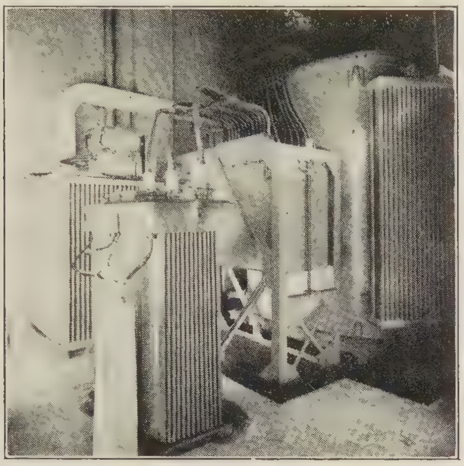


Fig. 9—2500-Kv-a., Step Induction Regulator Equipment

minus the voltage of one winding of the series transformer. There will be no change, therefore, in voltage if the second double secondary winding is connected to tap 2 so that its voltage is subtracted from the tap. The voltage may be increased further by disconnecting the auxiliary winding from tap 1, and rotating the regulator rotor so that the voltage of the second auxiliary winding plus the voltage of one winding of the double secondary winding is added to tap 2. The connections are then changed as before, so as to subtract the voltage of one winding of the series transformer from tap 3. Further increases of voltage are obtained beyond tap 3 in a similar manner.

An interesting application of the step induction regulator principle is illustrated in Fig. 9, where the voltage applied to a 2500-kv-a., synchronous converter is varied in the ratio of 2 to 1, giving a voltage range of 50 per cent in smooth transitions. By the use of voltage regulating equipment of this kind it is possible to cover a wide voltage range without the use of booster type converters.

In Fig. 10 is illustrated the possible compact and simple arrangement of step induction regulator equipment with all moving parts external to the main unit but with the series transformer inside the main case. The selector and transfer switches are mechanically operated contactor switches driven by the regulator in the proper sequence.

## Comparison of Step Type and Step Induction Regulator Methods

The step induction regulator is well adapted for use where bus or transmission circuit voltage is to be controlled, particularly where automatic control is desired. In this case, automatic control merely calls for a voltage actuated relay with time delay, giving a much more simple control equipment than is possible with the step type equipment. When automatic control is used, the number of tap changing operations is usually greater than otherwise so that the step induction regulator units are particularly adaptable on account of the fact that there is no burning of the contacts and therefore less maintenance required.

When the range in taps to be covered is not too large, and if small steps are not required, the step type equipment is more desirable on account of the somewhat simpler equipment.

## Separate Regulating Units

The tap changing equipments heretofore considered have been applied directly to the transformer unit. On account of the fact that no additional transformer units are required, this generally gives the cheapest, most efficient and most compact equipment to change the voltage.

There are applications, however, where modifications of this simple arrangement are desirable.

In general, tap changing mechanisms are so far practicable for direct use in circuits up to 33,000 volts or carrying not more than 1200 amperes. By using these units in the star connection of solidly grounded systems

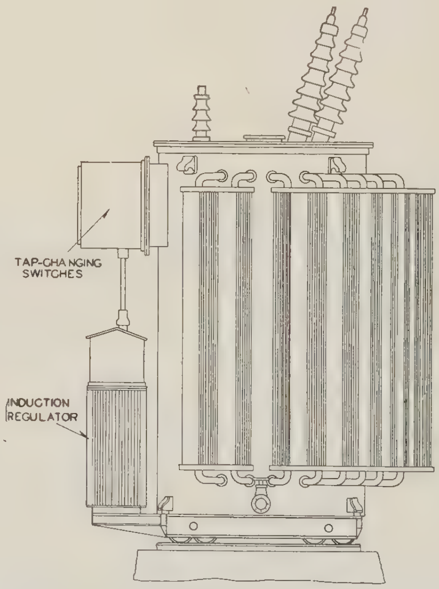



Fig. 10—Sketch of Transformer Provided with Step-Induction Regulator Equipment Built Integral with It

it is possible to apply them to transformers of much higher voltage by placing the tap changer in the grounded end.

In case of delta connections above 33,000 volts or ungrounded star windings of higher voltage, the use of a separate regulating unit becomes desirable at present.

The use of a separate regulating unit may be desirable also from other considerations. For example, if it is desired to obtain voltage control with transformers already installed, the separate regulating unit becomes

very useful. In some cases the need for voltage regulation may not be permanent, so that a separate regulating unit may be used with the idea that it may later be transported to some other location.

The use of separate regulating units, however, is accompanied by the requirement of more floor space, lower over-all efficiency on account of the extra transformers required, higher installation cost on account of the interconnections, etc., required between the regulating unit and the main unit.

Fig. 11 illustrates schematically the winding arrangement for a separate regulating unit. By suitably

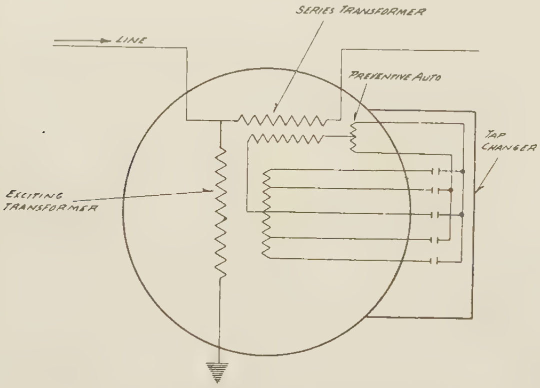



Fig. 11—Schematic Diagram of Separate Regulating Unit

arranging the ratios of the respective series and exciting units, the tap changing equipment may be used to cover a wide range of applications. Both the series and exciting transformers may be mounted in the same case, to reduce the number of bushings and simplify the connections and installations.

In the case of equipment for tap changing under load designed to operate on high-voltage ungrounded units, the auxiliary series and exciting windings may be built into the same unit in such a way as to reduce the number of auxiliary windings and cores and increase the over-all efficiency. Assume, for example, a unit with tap changing under load required on a 120,000-volt delta winding. The series transformer as shown in Fig. 12 may be used but the exciting transformer in the separate regulating equipment may be replaced by a third winding in the transformer as shown.

## Combination Voltage and Phase Angle Control

When systems become larger and interconnections become more frequent, cases will arise where phase-angle control, as well as voltage control, may be required to obtain satisfactory results. This condition will exist where a substation is supplied from two sources with interconnecting lines of different impedances.

It appears that the control necessary will be of the order of plus or minus 10 per cent in-phase voltage with a phase-angle control of approximately plus or minus 6 deg. This means that an in-phase component of plus or minus 10 per cent, and a quadrature component of plus or minus 10 per cent, each independently adjustable, should be super-imposed upon one of the lines at some suitable point.

These problems may be worked out, using two induction regulators, two transformers, or by means of a single multi-winding transformer.

## Regulation Methods

Under this scheme, taking a 24,000-volt line carrying 25,000 kv-a. as an example, two 1250-kv-a., three-phase, induction regulators, adapted for 5 per cent regulation on 25000 kv-a. and connected in series may be used. The primaries of these regulators are energized by means of a three-phase transformer, 24,000 to 4800 volts, 3300-kv-a. capacity. The output of the two regulators in series may be stepped up by means of a 2500-kv-a. series transformer so as to buck and boost the 24,000-volt line 2400 volts in either direction due to the two 5 per cent windings in series. Because of the fact that a three-phase regulator rotates the voltage vector,—that is, it is fixed in magnitude but is variable in phase,—the first regulator will add to the line voltage a voltage vector which is equal in magnitude to 5 per cent of the line voltage but whose phase angle with respect to the line voltage, (depending upon the relative position of the rotor and stator of the regulator), may swing to any position in a complete circle pivoted upon the end of the line voltage vector. The regulator

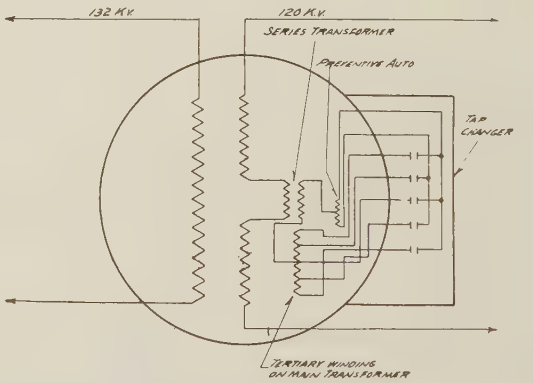



Fig. 12—Schematic Diagram showing Applications of Low-Voltage Tap-Changing Equipment to High-Voltage Transformers

itself may be supplied with slip-rings so that it is capable of continuous rotation. The terminal voltage of the regulator is therefore represented by a circle of radius 5 per cent. To this, a second regulator is connected in series having an independent control, the terminal voltage of the second regulator describing a 5 per cent circle having its center located on the circle described by the first regulator, with the result that the terminal voltage of the second regulator may be adjusted at any point within a radius equal to 10 per cent and may therefore give a phase angle control of the line voltage of approximately 6 deg. and also a maximum in-phase buck or boost of 10 per cent either way.

### Transformer Method

In the second method, two transformers of 2500-volt capacity each may be used with primaries wound for 24,000 volts and secondaries wound for 2400 volts, each rated for 24,000 volts series connection with the line and equipped with tap changing under load covering a range from plus 2400 volts to minus 2400. The first transformer is arranged with its primaries star connected so that the secondary is in phase with the line. The second transformer has a delta-connected primary and by properly selecting the secondary winding, a secondary in quadrature with the line is obtained. These two windings are placed in series with each other and with the line, and it is therefore possible to impose upon the line an in-phase voltage component of 10 per cent plus or minus and also a quadrature voltage component of 10 per cent plus or minus, each being controlled independently. By a manipulation of the two transformers in effect, it is evident that any degree of in-phase voltage regulation and any degree of phase-angle control within the limit of the apparatus may be obtained.

The losses in the case of the regulator method are approximately double the transformer method.

### Multi-Winding Transformer Method

By using a multi-winding transformer, the equipment may be still further simplified. Instead of using two transformers a single three-phase, three-winding transformer may be used. One winding is the exciting winding and the others are connected to give two voltages in series but displaced from each other by 60 deg. This would take the place of the two separate transformer windings in true quadrature. This arrangement results in a very decided decrease in the size of the transformer tank and also an increase in the over-all efficiency of the transformation, and results in a considerable reduction in cost.

In either of transformer equipments, any of the types of tap changing equipment may obviously be used.

### Conclusion

The development of reliable sturdy apparatus for changing transformer voltage ratio under load has opened up a new field with enormous possibilities. While it can be seen that equipment of this nature is not inexpensive, yet it will generally be found that if voltage control of large capacity is desired, the use of transformers arranged for changing taps under load will be found economically desirable.

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# Recent Investigation of Transmission Line Operation

BY J. G. HEMSTREET[1]

Associate, A. I. E. E.

***Synopsis.**—This paper discusses transmission line operating experience on the 140,000-volt isolated neutral system of the Consumers Power Company, Michigan.*

*Careful inspections and tests have been made to determine the conditions existing relative to insulator flashover and the findings and results are shown by tables and curves.*

*Ground resistance or soil conditions appear to have a very decided effect on the number of flashovers on the various lines. The necessity of providing suitable arc protection to the line conductors is shown, as is also the soundness of certain theories and recommendations for increasing the reliability of transmission lines, based upon laboratory experiments.*

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### Introduction

The design of an insulation system for high-voltage transmission lines that will be immune from failure during lightning storms or other abnormal conditions, is one of the most important problems confronting the transmission engineer at the present time. This is becoming increasingly so with the interconnection of large systems and the more exacting requirements of the consumers.

The experience of those who have been operating some of the larger systems should be of assistance in designing, in so far as possible, to guard against the difficulties that have been encountered, and it is with this thought in mind that the data in this paper are presented, as well as to add to the information on operating experience already available; also as a further check on certain theories and designs that have been and are proposed for the greater reliability of high-voltage transmission lines. This paper relates some experiences and the results of investigation of transmission line operation with particular reference to insulator flashover on the 140,000-volt system of the Consumers Power Company in Michigan. A map of this system is shown in Fig. 1.

### History

The matter of insulator flashover became of some concern a few years ago as the system increased in size. The flashovers in some cases caused voltage disturbances or circuit breaker operation and in a

1. Supt. of Operation, Consumers Power Co., Jackson, Mich.

*Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June* 20-24, 1927.

few instances failure of the line due to burning of the conductor or hardware at the lower end of the insulator string. The earlier lines were not equipped with any form of arc protection but in 1920, standard 15-in.

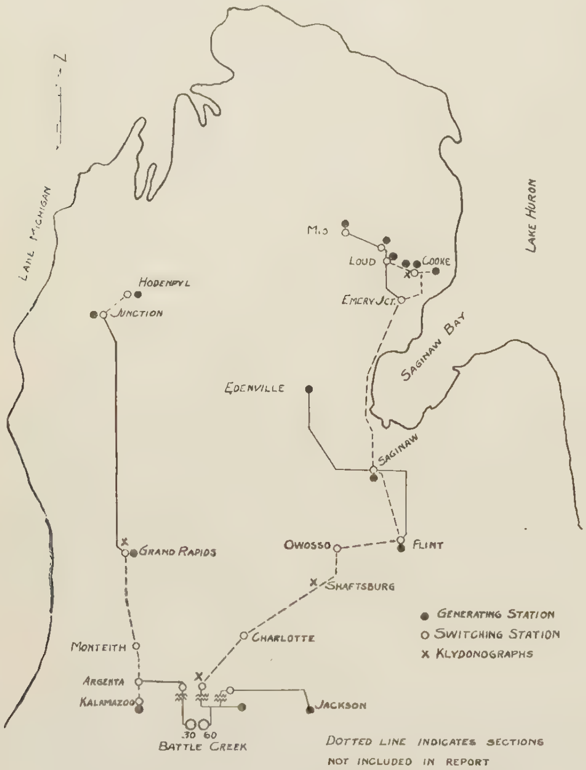


Fig. 1—Map of 140,000-Volt System

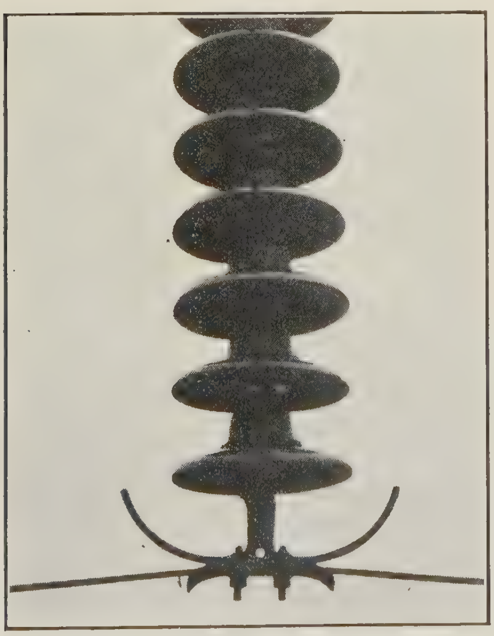

Fig. 2—Type of Arcing Horn Used

arcing horns, (shown in Fig. 2), were installed on the Argenta-Battle Creek section which at that time was added to the system. Later in the year, the Jackson-Battle Creek section was added and was also equipped with the standard arcing horn. The Edenville-Saginaw-Flint sections were added in 1924. At the time these last two sections were being designed, there was considerable discussion as to the nature of the transients, set up in high-voltage systems, that caused flashover, and based upon the theory that the trouble was due to rather sustained high frequency conditions[2], started by the original lightning discharge or some other cause, the insulator flux control was offered as a means of raising the flashover voltage of the insulator, as well as providing a horn as protection to the conductor. The Consumers Power system being delta-connected throughout, the possibility of the existence of severe high-frequency disturbances was

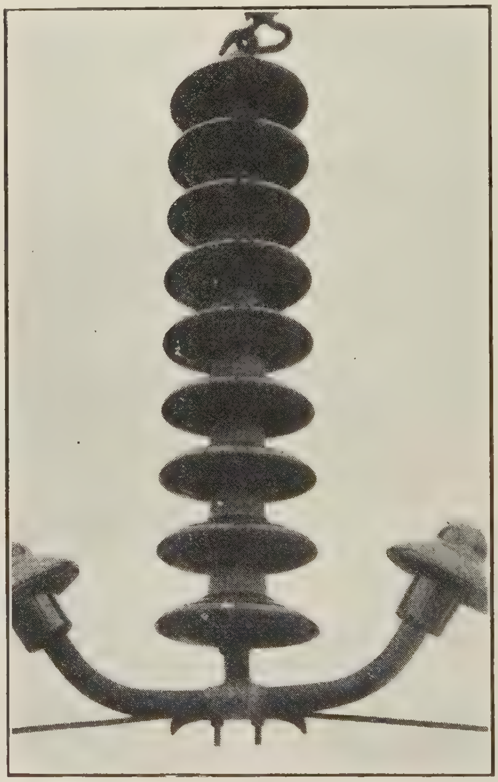

Fig. 3—Flux Control Assembly

thought to be more likely at the time than would be the case on other systems operating with the neutral grounded, and this was thought possibly to be the cause of some of the trouble. These last two sections of line were equipped with the flux control, as shown in Fig. 3. All of the arcing horns and flux controls were installed on the lower end of the insulator strings only.

The development of the klydonograph[3] offered a means of determining the nature of the transients and four cf these instruments were in service during 1925.

At the close of the 1925 lightning season, it was

2. A. O. Austin, "Insulation Systems," paper, Second International High-Tension Congress, Paris, 1923.

3. J. F. Peters, "The Klydonograph," *Electrical World*, April 19, 1924.

decided to make a careful inspection of the two sections of the transmission line added to the system during 1924. There had been no failures directly traceable to these sections but it was thought desirable to determine the exact conditions. The inspection was carried on with considerable care, an especially trained crew of men climbing each tower and carefully inspecting the insulators, conductors and all parts of the tower tops, to locate any burns or evidence of insulator flashovers. Later, the inspection was extended to other parts of the system to obtain the comparative data, and also to locate and eliminate any weaknesses due to damaged conductors or other equipment. In only a very few cases could the damage be detected from the ground, nor had it been found by the regular patrol service.

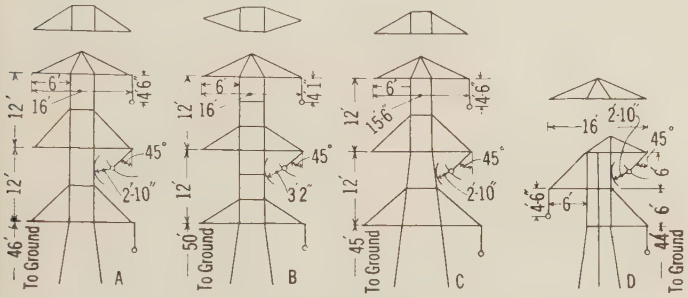


FIG. 4—TYPES OF TOWERS SHOWING DIMENSIONS AND CLEARANCES

## DESCRIPTION OF SYSTEM

The system as shown on the map, Fig. 1, consisted of 431 mi. of line operated at 60 cycles in the Eastern part of the state and 186 mi. operated at 30 cycles in the Western part of the state. All 60-cycle lines are electrically connected through the busses at the station except the Jackson-Battle Creek section, this being isolated from the remainder of the system by transformers at Battle Creek. The 30-cycle lines are all connected. The two systems are interconnected through a 15,000-kv-a. frequency changer at Battle Creek. Sections shown by solid lines are those that were closely inspected and are referred to in the data in this paper. Those sections shown by broken line were put into operation prior to 1915 and were originally equipped with the older type cap and pin insulators, quite a large number of which have since been replaced. The shuffling of the insulators in replacing the defective ones made it impossible to obtain satisfactory comparative data on these sections. Capacities of generating equipment totaled approximately 225,000 kv-a. feeding into the 60-cycle system and 100,000 kv-a. into the 30-cycle system in 1925.

Fig. 4 shows the types of construction conductor clearance and separation, height of tower and other details of construction. There were no ground wires installed on any part of the system at that time, and one circuit was in place on the towers in all cases. The lines are equipped with Ohio Brass No. 25622 insulators.

## RESULTS OF INSPECTION AND INVESTIGATION

The inspection data cover a total of 305 mi. of line scattered throughout the state. The period of operation of the different sections varies from two to tne

TABLE I

SUMMARY OF FLASHOVER DATA

| Section of line | Junction-Grand Rapids | | Edenville-Saginaw | | Saginaw-Flint | | Argenta-Battle Creek | | Battle Creek-Jackson | | Mio-Loud | | Loud-Emery Jtc. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frequency of current, cycles | 30 | | 60 | | 60 | | 30 | | 60 | | 60 | | 60 | |
| Length of line—miles | 101 | | 40 | | 44 | | 26 | | 43 | | 32 | | 19 | |
| Conductor | 110,000 cm. Copper | | 2/0 Copper | | 3/0 Copper | | 4/0 A. C. S. R. | | 2/0 Copper | | 110,000 cm. Copper | | 110,000 cm. Copper | |
| Number of years in operation | 8 | | 2 | | 2 | | 5 | | 5 | | 10 | | 9 | |
| Total number towers | 1,057 | | 348 | | 352 | | 270 | | 438 | | 301 | | 188 | |
| Nominal length of span—feet | 530 | | 660 | | 660 | | 530 | | 530 | | 530 | | 530 | |
| Average height lowest conductor—feet | 31 | | 34 | | 34 | | 32 | | 32 | | 28 | | 28 | |
| Number disks in insulator string—susp | 10 | | 9 | | 9 | | 10 | | 10 | | 10 | | 10 | |
| strain | 12 | | 12 | | 12 | | 12 | | 12 | | 12 | | 12 | |
| Arc protection | None | | Flux control | | Flux control | | 15 in. horns | | 15 in. horns | | None | | None | |
| Number suspension strings | 2,811 | | 1020 | | 1047 | | 843 | | 1345 | | 738 | | 509 | |
| Number strain strings | 744 | | 98 | | 210 | | 132 | | 173 | | 330 | | 110 | |
| Total number strings, insulators | 3,555 | | 1118 | | 1257 | | 975 | | 1518 | | 1,068 | | 619 | |
| Reference Fig. 4 | A | | B | | B | | C | | D | | D | | C | |
| | No. | Per cent | No. | Per cent | No. | Per cent | No. | Per cent | No. | Per cent | No. | Per cent | No. | Per cent |
| Number suspension strings flashed over | 486 | 17.3 | 34 | 3.3 | 56 | 5.3 | 73 | 8.7 | 75 | 5.6 | 43 | 5.8 | 27 | 5.3 |
| Number strain strings flashed over | 39 | 5.2 | 3 | 3.1 | 5 | 2.4 | 1 | 0.8 | 11 | 6.4 | 18 | 5.5 | 2 | 1.8 |
| Total number strings flashed over | 525 | 14.7 | 37 | 3.3 | 61 | 4.9 | 74 | 7.6 | 86 | 5.7 | 61 | 5.7 | 29 | 4.7 |
| Number flashovers, top conductor | 217 | 41 | 31 | 84 | 39 | 64 | 40 | 54 | 45 | 51 | 35 | 57 | 16 | 55 |
| Number flashovers, middle conductor | 161 | 31 | 5 | 13 | 13 | 21 | 20 | 27 | 25 | 29 | 11 | 18 | 6 | 21 |
| Number flashover, lower conductor | 147 | 28 | 1 | 3 | 9 | 15 | 14 | 19 | 16 | 20 | 15 | 25 | 7 | 24 |
| Number cases of damaged conductor | 345 | 66 | 2 | 5.3 | 7 | 11.5 | 2 | 3 | 4 | 5 | 23 | 38 | 7 | 24 |
| Number flashovers per mile of line per year | 0.650 | | 0.461 | | 0.691 | | 0.570 | | 0.405 | | 0.180 | | 0.170 | |
| Failure of line due to burned wire or hardware | 3 | | None | | None | | None | | None | | 1 | | None | |

years. The country over which the lines are built is very flat, the maximum variation in height over any section being less than 200 ft. Therefore, the lines follow closely the contour of the ground.

Laboratory measurements by Peek[4] indicate that the voltage due to lightning storms in the delta-connected system such as this would be slightly less than in systems operating with the neutral grounded, all other factors, of course, being equal, and this is also borne out by comparison with the experiences on systems of the other type, so it would seem that these data should be fairly representative of results that might be obtained in other locations under similar conditions insofar as the number of flashovers are concerned.

Table I gives some additional construction details and a summary of the number of cases found where flashovers had occurred, their location on the tower, extent of damage to the line conductor, and other information. A study of this table shows some rather interesting conditions.

Rather wide variations in the results on different sections will be noted. The Junction-Grand Rapids, Mio-Loud and Loud-Emery Junction lines of very similar construction and not equipped with arc protection show a variation from 0.17 to 0.65 flashover per mile of line per year after 8, 10 and 9 years operation respectively.

The popular reason for this would be the variation in the severity and frequency of storms in the two localities. It is a fact that the Junction-Grand Rapids line runs north and south directly across the path of a great many storms as they pass inland off Lake Michigan, but on the other hand the Mio-Loud line follows very closely the bed of the Au Sable River, nearly east and west and lies parallel to the course of a great many storms which it is said by many have a tendency to follow the water courses. Possibly these factors may influence the results one way or another, but other conditions peculiar to the different lines may perhaps have a very decided influence on the operating results that have been obtained.

## Height of Line Above Ground Soil Conditions, Ground Wire and Other Factors

Measurements and tests made by Peek[5], have shown (a) that the voltage gradient between cloud and earth in the air under a storm cloud is approximately 100 kv. per ft. under severe conditions, and (b) that the voltage induced in the transmission line will vary with the height of the line above the ground, amounting to 30 to 50 kv. per ft. depending upon the closeness of the storm to the line and other factors. Also that placing a ground wire above the line reduces the lightning disturbances from 30 per cent to 50 per cent. The induced voltage, where the wires are placed in a vertical plane, should therefore be lowest in the conductor nearest the ground and correspondingly high in the other conductors.

The data showing the number and per cent of flashovers occurring on the top, middle and lower conductors in Table I check quite closely with this law. There are some slight discrepancies, as on the Mio-Loud and Loud-Emery Junction lines, and in some cases flashovers occur on the middle and lower conductors and not on the top wire, but in general, agreement is noted. There is, however, quite a wide variation in the results in this respect between the individual lines. On the Edenville-Saginaw and Saginaw-Flint lines, equipped with flux controls, the percentages of flashovers on the middle and lower conductors are lower than on other sections of the line. This would tend to indicate that the flux control has raised the flashover voltage of the string to some extent, but not sufficiently to keep

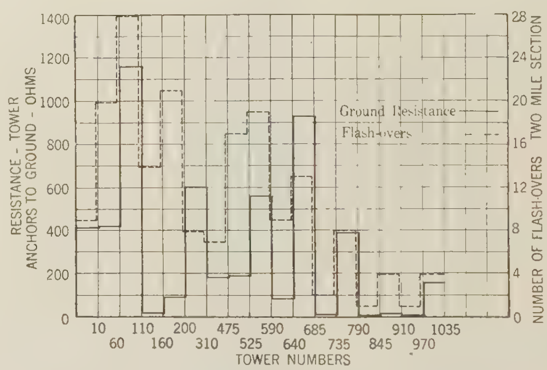


Fig. 5—Number Flashovers Compared to Ground Resistance, Junction-Grand Rapids Line

the lower conductor entirely free of flashovers. On the Edenville-Saginaw line, there was but one case of flashover on the lower conductor over the two-year period. The sphere-gap effect of the tubular horn used with the flux control may perhaps have some effect, together with the shielding effect of the control insulator.

A comparison of the Edenville-Saginaw line with the Junction-Grand Rapids line shows a wide variation in this respect. The Junction-Grand Rapids line shows the smallest percentage of flashovers on the top phase, while the Edenville-Saginaw line shows the greatest with a wide variation over the three wires in spite of the higher nominal elevation of the conductors. In looking for other reasonable explanations for this difference, the possibility of soil conditions being somewhat responsible is suggested. The curves in Figs. 5 and 6 show a comparison of ground resistance measurements with the number of flashovers on the Junction-Grand Rapids and the Battle-Creek-Jackson lines.

The ground resistance was measured between the tower anchors, (which are of the basket type), and ground rods driven into the ground approximately 24 ft. from the base of the tower. Complete resistance

4. F. W. Peek, Jr., *Lightning and Other Transients on Transmission Lines*, A. I. E. E. Trans., Vol. XLIII, p. 1212.

5. F. W. Peek, Jr., *Lightning and Other Transients on Transmission Lines*, A. I. E. E. Trans., Vol. XLIII, p. 1212.

measurements of all the towers on the line were not available but at points approximately every five miles along the line, the ground resistance of several towers was measured. An average was calculated from each group, and from this data, the ground resistance curve was plotted. The broken line shows the number of flashovers occurring within one mile in each direction from the group of towers whose resistance was measured. That there is some relation between ground resistance and the number of flashovers seems apparent in the fact that both increase and decrease correspondingly with one or two exceptions which might be because of abnormal local conditions.

Peek[6] has called attention to the "water level" below the surface of the ground as being the effective ground level, and has stated that under equal conditions, an induced voltage is higher in dry sections because of the fact that the flux extends from cloud to water level, the effect being that of increasing the height of the line.

Referring to Fig. 5, it is noted that the ground resistance along the Junction-Grand Rapids line is very high,

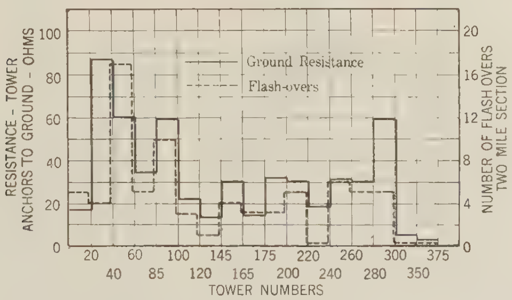


FIG. 6—NUMBER FLASHOVERS COMPARED TO GROUND RESISTANCE, BATTLE CREEK-JACKSON LINE

reaching a maximum of 1200 ohms. The soil along this line is very dry and sandy and in some small sections, it is almost devoid of vegetation. The country along this line is slightly more rolling in places than along some of the other lines, but not enough, apparently, to affect conditions to any extent. The high-resistance measurements were not confined to the higher points, but were found in all locations. The soil on the Edenville-Saginaw line represents perhaps the other extreme, being low and marshy with a considerable amount of heavy clay soil, and the water throughout this district is very salty; in fact, there are several chemical manufacturing plants obtaining their products from the brine pumped from the ground. A sufficient number of ground resistance measurements along the Edenville-Saginaw line were not available to plot a curve, but those taken indicate a resistance of not over four ohms.

The conditions along the Battle Creek-Jackson line show lower ground resistance than the Junction-Grand Rapids line, varying between 10 and 100 ohms. The conductors being lower probably helped, but this was offset to some extent by the small arcing horns which probably increased the number of flashovers. The percentage of flashovers on the top conductor on this line is smaller than any other except Junction-Grand Rapids, and the other lines follow this trend, varying in proportion to the ground resistance. The location of the Mio-Loud line along the river probably helped to keep down the number of flashovers on account of the moist soil close under the line, also the triangular construction lowering the two top wires, undoubtedly helped to some extent.

With the increased effective height of the lines with higher ground resistance, all three of the conductors are well within the flashover voltage range and the effect of the difference in the height of each of the three conductors is proportionately smaller. On the Edenville-Saginaw line apparently the closer proximity of the lower wire to the effective ground level makes it almost immune to flashovers in spite of the higher nominal span. It also lowers the number of flashovers on the middle wire, but the height of the top wire raises it to within the range of the flashover voltage. The shorter strings of insulators on this line undoubtedly had some detrimental effect. Results of this kind suggest that the lines should be so constructed that all three conductors will be a minimum distance from ground or in a horizontal plane.

Comparison of the Junction-Grand Rapids and Edenville-Saginaw lines is of interest from the standpoint of the type of construction and possible effect of a ground wire. It is probable that if the Edenville-Saginaw line had been constructed with the horizontal configuration instead of its present form, this line would be very free from lightning trouble even without ground wires. On the other hand, the Junction-Grand Rapids line, with the same construction, would probably require one or more ground wires to produce equal results, and care would have to be taken that the ground wires were provided with a connection to water level or a good ground.

It has been supposed that flashovers might increase with the mileage of line, but the results on the Jackson-Battle Creek line, which is separated from the remainder of the system, does not bear out this theory and inasmuch as the lightning surges travel but a short distance, it is reasonable to believe that there would be no great difference.

Reports of operating results on lines in different sections of the country indicate quite a wide variation in results from the standpoint of trouble during lightning storms. In some cases, excellent results are obtained with but moderately insulated lines, and in other places, considerable trouble is experienced on much more highly insulated lines. It is apparent, however, that at least some of the conditions that cause these discrepancies are being cleared up, and before constructing lines in the future, the soil conditions and

6. F. W. Peek, Jr., *Lightning and Other Transients on Transmission Lines*, A. I. E. E. TRANS., Vol. XLIII, p. 1213.

other factors not heretofore taken into consideration will be studied before the design is completed and more definite information obtained concerning the amount of insulation, number of ground wires, and other factors necessary to produce a line that will be as free as possible from these troubles.

### Effectiveness of Arc Protection

Comparing the lines equipped with the flux controls and arcing horns with the others, the rather remarkable efficiency of the arc protection in reducing the damage to the conductor is noted. A decrease from 66 per cent, 38 per cent and 24 per cent on the lines not equipped to 3 per cent and 5 per cent on those equipped with arcing horns and 5.3 per cent and 11.5 per cent on those with flux controls is shown, the arcing horns being somewhat more effective than the flux controls. It will also be noted that there have been no failures due to burning of the conductor or insulator hardware on any line equipped with either type of horn which also emphasizes the advisability of providing some form of arc protection.

The conditions that were found on the Junction-Grand Rapids line with its 66 per cent of burns offer an excellent example of what may be expected of a line constructed in a locality of this kind without arc protection to the conductor or some means of holding down the lightning potentials.

It will be noted that the number of failures of the line due to the arc burning off the conductor, or some part of the insulator string at the time of the flashover, is rather small. There have been a total of only three in the eight years of operation on the Junction-Grand Rapids line and one on the Mio-Loud line. This, of course, is an excellent service record. However, of the 345 cases of damage found on the Junction-Grand Rapids line, a great many were so serious as to necessitate immediate repairs. Where the damage is not so great, there is, of course, some weakening of the conductor. This creates the hazard of failure at some future time when abnormal mechanical stresses are imposed upon the conductor, such as during severe sleet storms, and some failures of conductors on this line during sleet storms that have occurred in the past are now suspected of having been at least partly due to this weakened condition of the wire.

Aside from the damage to the conductor, the arcs do not seriously damage the other equipment. In some instances the top or lower disk is broken, but there has not been a sufficient amount of this to warrant the installation of protective equipment at the top of the string. In most cases there is no damage apparent from the ground. The current in the arc on the isolated system is smaller than if the neutral were grounded, which undoubtedly, helps to a considerable extent.

The arcs shift around to a considerable degree over the surfaces upon which they are playing. The theory has been advanced that the arc causes a separate burn with each half cycle. The appearance of the spots tends to bear this out. The small round burns are found to be deeper and more severe on the 30-cycle than on the 60-cycle system due apparently to the greater duration in each location at the lower frequency. Using the number of spots found as an indication of the length of time the flash over exists it is thought that a great many of the flashovers are of very short duration, considerably less than one second, others, however, hold longer and evidently are the ones that cause the more serious damage.

The data also show that there are quite a number of flashovers on towers where the insulators are in the strain position. In most cases, however, the breakdown occurs between the jumper loop and the tower and it is believed in some instances that the loop is not always at a maximum distance from the tower due to wind conditions or distortion of the conductor due to other causes. Consideration in this case is being given to

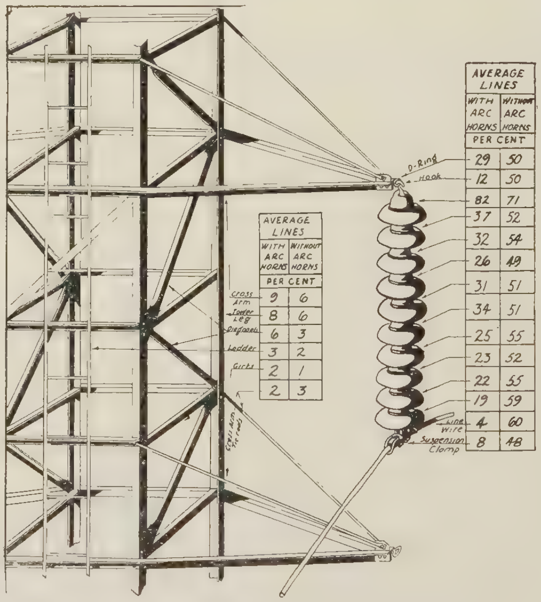


Fig. 7—Relative Location of Burns Caused by Flashovers

the use of methods of holding the loop away from the tower at the maximum distance under all conditions.

In Fig. 7 an effort has been made to show the conditions found relative to the travel of the arc and the cascading of the insulator strings. A typical tower top with the location of the burns that were found on lines with and without arc protection is shown. The figures opposite the insulator string and tower show the percentage of burns found on the different pieces of equipment with reference to the total number of flashovers. It is noted that in practically 50 per cent of the cases where no arc protection is used, the various caps of the insulators are burned. The number burned in each flashover varies, but the percentage of each is quite uniform over the total number of flashovers. The amount of cascading is not so great where horns are used varying from 19 per cent to 37 per cent on disks

below the top one, but the amount of flashing to the tower basket is greater. This is particularly so with the flux controls and might indicate an effort on the part of the control to perform its duty of keeping the flashover away from the string. On the Junction-Grand Rapids line, about 15 per cent of the strings, where flashover had occurred, were found with all of the caps burned. On the other lines, however, this was of rare occurrence.

Fig. 7 shows again the very marked decrease in the amount of damage to the line conductor and clamp where arcing horns are used. These data are also of interest in showing that a very high percentage of the

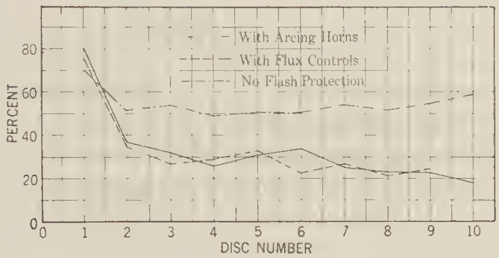


Fig. 8—Cascading of Insulators with and without Arc Protection

flashovers occur over the insulator string and does not take place between the conductor and tower independent of the insulator string as has been thought.

The cascading and burning of the caps, except at the end of the strings, apparently takes place at the time of the initial flashover, as tests that have been made on various types of arcing horns show that there is a strong tendency for the power arc to blow away from the string in almost all cases, regardless of the type of arc protection in use. During part of the 1926 lightning season, there was a new line between Argenta and Battle Creek on the opposite side of the tower from the old one which had not been put in service and had both ends grounded. An inspection showed that several flashovers had occurred on this dead line and the caps show burns similar to those on the live lines.

The curves in Fig. 8 also show the amount of cascading quite clearly on the lines with and without arc protection. The curves show the effectiveness of these particular types of arc protection in reducing the amount of cascading.

## Measurement of Surges

Four klydonographs were in service on the system during the year 1925 and as indicated in Fig. 1, instruments were placed at Cooke, Shaftsburg and Battle Creek on the 60-cycle system and at Grand Rapids on the 30-cycle system. These instruments were in service for a period of about eight months, which included the lightning season.

In Table No. II is a summary of the record of the four installations and shows that a total of 567 surges of between 1.5 and 10 times normal voltage to ground were recorded. It is noted that only the lightning surges reach values in excess of five times normal and are undoubtedly the cause of the insulator flashover. This checks closely with operating records inasmuch as flashovers occur during lightning storms and in localities where the storms are known to be present. With the klydonographs so widely scattered, these registrations can only be taken as a partial record of the number and magnitude of the surges due to lightning, as this type of surge is of steep wave front and is quickly attenuated. In one case the klydonograph at Grand Rapids registered 10 times normal voltage on one phase and nine times on the other two. The maximum surge recorded was during a severe lightning storm directly over the Cooke station. At this time the potentiometer, which was of the ring type, supported on post type insulators, flashed over from the top ring to the bottom of the insulator column. The klydonograph flashed over between all three terminals and to ground and produced a very large image across the film. It is thought that about 15 times normal voltage would be required to flashover the potentiometer so it is evident that voltages in excess of this were present in the transmission line.

The insulator strings themselves are perhaps the best indicator of the magnitude of the surges. Peek[7] has shown that the lightning sparkover of a string of suspension units such as used on these lines is between

TABLE II

NUMBER AND VOLTAGE OF VARIOUS KINDS OF SURGES ON TOTAL SYSTEM AS RECORDED BY KLYDONOGRAPH

| Number times normal crest voltage to ground | | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | + | 125 | 36 | 8 | 10 | 6 | 3 | 1 | 2 | | | | | | | | 191 |
| Switching surges | − | 1 | 1 | | | | | | | | | | | | | | 2 |
| | − + | 10 | 4 | 3 | 1 | 1 | | | 3 | | | | | | | | 22 |
| | + | 64 | 16 | 13 | 6 | 2 | 4 | 2 | | 1 | 1 | | 2 | | | | 111 |
| Lightning surges | − | 1 | | 1 | 1 | | | | | 1 | | | | 1 | 2 | 1 | 8 |
| | − + | 2 | 12 | 1 | 8 | 2 | 1 | 3 | | | 2 | | | | | | 31 |
| Arcing ground surges | − + | 11 | 25 | 35 | 25 | 8 | 8 | 4 | 2 | | | | | | | | 118 |
| | + | 53 | 11 | 5 | 3 | | | | 1 | | | | | | | | 73 |
| Surges of unknown origin | − | 1 | | | | | | | | | | | | | | | 1 |
| | − + | 7 | 2 | 1 | | | | | | | | | | | | | 10 |
| Total | | 275 | 107 | 67 | 54 | 19 | 16 | 10 | 8 | 2 | 3 | | 2 | 1 | 2 | 1 | 567 |

7. F. W. Peek, Jr., *Lightning and Other Transients on Transmission Lines*, A. I. E. E. Trans., Vol. XLIII, p. 1215-16.

1,200,000 to 1,400,000 volts. The results indicate that voltages of this magnitude or greater are present on the lines and also show the correctness of the use of a potential gradient of from 30 to 50 kv. volts per ft. in calculating the voltage that may be present in lines close to lightning storms.

The surges due to switching and arcing grounds are much less severe than those caused by lightning and insofar as the line insulators are concerned, are not of great concern. Undoubtedly the registrations made by them are nearer to their true value than is the case with lightning surges, as they travel greater distances along the line.

The records covering the klydonograph installations at the different locations did not vary to any great extent although the instrument at Grand Rapids recorded a greater number of more severe lightning surges than the other instruments which undoubtedly is consistent with the other flashover data, as this instrument was connected to one end of the Junction-Grand Rapids line where the most severe conditions are thought to exist.

### Relay Protection

The relay scheme in use has not been shown. This has been developed along with other parts of the system over the period of years covered by this data, but in general it consisted of the usual standard relays.

In 1926 a system of ground relays operated by the unbalanced residual current in the line when a ground occurs was installed on the 60-cycle system and very good results have been obtained[8].

We have been unable to connect up all of the flashovers with surges or disturbances on the system, and it is thought that in many cases the arc extinguishes itself without starting a disturbance that would cause surging in voltage or circuit breaker operation. This is perhaps another peculiarity of the isolated system.

### Insulating and Arcing Devices

Assuming that the lightning sparkover voltage of the insulator string varies with its length, it is apparent that there is an advantage in increasing the length of the string provided sufficient clearance is maintained from other parts of the structure. Insulators of rather close spacing are in use in a great many instances. One object is to reduce cascading as much as possible; also to reduce the stress across the individual units. The data on this system, however, indicate that even with a very closely spaced unit the cascading takes place. With the improvements that have been made in insulators during the past few years, the danger of puncture is much less than heretofore, so that it would appear that there is considerable gain in protection to the line from lightning flashovers as well as from the cost standpoint in using the wider spaced unit in obtaining a longer string.

In sections of the country removed from the sea coast and where trouble from fog or dust is not experienced, the use of wooden pole structures in the place of steel towers appears from the insulation standpoint to have some merit. Advantage is taken of the insulation of the wooden structure which apparently is considerable, and in certain locations like in the vicinity of the Edenville-Saginaw line, wood pole lines with the conductors carried in a horizontal plane at the minimum distance from the ground might provide a line that would be very free from lightning trouble, without the use of ground wires.

The choice of an arcing attachment for the insulator string is somewhat of a problem. Various kinds of horns and rings are offered. Some are said to be more efficient than others in not only protecting the conductor and insulators from the arc, but bettering conditions around the insulator string so that the flashover is not so apt to occur. Experience on this system has been confined to the types of horns shown in Figs. 2 and 3 and has demonstrated the high efficiency of the small arcing horn as protection to the conductor, but which, like all plain horns, undoubtedly lowers the flashover of the string. Systems where more severe arc conditions exist might not obtain as good protection and would have to consider their own local conditions. There does not appear to be any marked difference in protective value between the various kinds of plain horns. The power arc has a strong tendency to blow out away from the insulators in most cases, but devices that will prevent the cascading of the string at the time of the initial flashover might be of considerable value.

### Remedial Measures

Ground wires are being installed on all tower lines now under construction on this system and are either being installed or contemplated for at least part of the older sections of the system.

On the Saginaw-Flint line, which has been completed for two years, a ground wire will be in place during the 1927 lightning season, and it is planned to secure data showing the effectiveness of this ground wire in reducing flashovers. There is a second line between these two places, shown on the map with a separation from two to eight miles, which has also been carefully inspected to determine its present condition in regard to flashovers. A number of surge recorders of the klydonograph type will be placed at frequent intervals along both of these lines and it is hoped to get a good comparison between the two lines with and without ground wire.

Ground resistance measurements are being made over a number of other lines with the idea of determining more definitely the effect of soil conditions and the location of the effective ground level and to determine the necessary protective equipment for future and also some of the present lines. It is planned to install arc

8. *Directional Ground Relay Protection of High-Tension Isolated Neutral Systems*, Breisky, North and King, Summer Convention, A. I. E. E., Detroit, Mich., June 20-24, 1927.

protection of some type on all of the lines whether or not ground wires are installed, as it is evident there will still be a number of flashovers in spite of the equipment installed to reduce the disturbance caused by lightning.

Consideration is also being given in some locations to use of the wooden pole "H"-frame construction as a means of increasing the insulation of the line and placing the conductors in a horizontal plane as close as possible to the ground. It would seem that this type of construction would give the maximum protection insofar as the lightning storms were concerned, provided some method is worked out to prevent the shattering of the poles and crossarms and the possible burning of the poles or crossarms in some localities due to leakage over the insulators.

Conductor clearance and separations have been increased on all new lines, and provisions made for the installation of longer insulator strings, if this seems desirable after the effectiveness of the ground wire has been determined.

On the strain type construction some means of holding the loop or jumper will be installed so that there will be no possibility of its coming close enough to the tower to cause flashovers.

### Conclusions

1. Transmission lines in sections where lightning storms are prevalent are subjected to extremely high voltages, which will cause quite frequent flashovers of the insulators unless constructed in such a manner, or protected so as to hold down this voltage.

2. The severity of the conditions affecting the line varies considerably in different sections due to local surroundings and perhaps the severity of storms.

3. Unless equipped with some type of arc protection, damage is very apt to result to the line conductors, which, if it does not cause failure at the time, weakens the wire and creates the hazard of failure at some future time.

4. Cascading of the arc over the insulator strings will take place to some extent in nearly all flashovers unless the string is provided with suitable preventative equipment.

5. Surges due to switching or grounds in so far as the line insulators are concerned do not appear to be of serious consequence.

6. Careful inspection of lines is warranted on account of the defects found that are not appearent from the ground, particularly on a system operating with isolated neutral.

7. It seems desirable that a thorough study, including conditions affecting the height of line, as well as the frequency and severity of storms, be made before a line is constructed to determine the necessary protective features.

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**Abridgment of**

# The Collection of Current From Overhead Contact Wires

BY R. E. WADE[1] and J. J. LINEBAUGH[1]
Non-Member Associate, A. I. E. E.

***Synopsis.***—*Up to a few years ago, the generally accepted limitations for the amount of current which could be collected from an overhead distribution system were from 300 to 800 amperes in heavy interurban service and between 800 and 1000 amperes, with a maximum of 1500 in the case of the Chicago, Milwaukee & St. Paul.*

*It is not possible to determine the limits of current collection by theoretical calculations nor by the experience on any particular installation. The tests described and analyzed in this paper were demonstrated on a four-mile track using special overhead construction of the twin trolley type with observation towers at several points to enable observers to carefully inspect commutation between the collector and the trolley wire.*

*Tests were also made to determine the temperature rise which would be obtained as a result of delivering, for a period of five minutes, a current of 5200 amperes to a standing locomotive. Further tests were made to determine what damage would result, if any, should a pantograph leave the wire while delivering currents as high as 4000 or 5000 amperes. Test data are included and description of the several types of overhead construction used.*

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### Introduction

THE problem of transferring current from overhead contact wires to moving cars and locomotives is one which cannot be solved by mathematics or laboratory tests. Neither can conclusions as to the limits of current collection be reached by experience on any particular installation.

There has been considerable discussion as to the amount of current that can be successfully collected from an overhead contact system. Except for standard railways, operating experience has been confined to the heavier types of interurban service, with current values of from 300 to 800 amperes, and heavy traction work such as the Chicago, Milwaukee & St. Paul Railway, where normal current collected with single pantograph varies between 800 and 1000 amperes, with a maximum of about 1500.

Those who have made a study of the subject know that there is a large number of factors to be taken into

1. Both of the General Electric Co., Schenectady, N. Y.

*Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 20-24, 1927. Complete copies upon request.*

account and that each of these factors is subject to considerable variation due to design, maintenance methods, or both; also that certain factors are essential for successful current collection on any given installation.

In view of the nature of the problem, as mentioned above, and the general interest in probable future requirements, a series of tests was conducted with the object of securing information as to the maximum amount of current that could be successfully collected from overhead contact wires with the conditions which are described later. These tests were made at Erie, Pennsylvania, on a section of track owned by the East Erie Commercial Railroad, and used by the General Electric Company for testing locomotives and cars. Following reconstruction of overhead contact system and completion of test runs, demonstrations of heavy current collection were given to engineers and railroad men on July 16, 17 and 18, and other dates, 1923.

These tests were planned and conducted in conjunction with the New York Central Railroad and the Cleveland Union Terminals Company.

It is thought that the importance of this subject, in connection with railway electrification work, justifies the compilation of a record covering the details of preliminary tests and investigations and the results as finally demonstrated.

Fig. 2—Test Train Consisting of Locomotive No. 18, Gondola

With loading rheostats and observation car

## Nature of Tests

Due to the fact that the capacity of the substation supplying power was limited to 6000 kw., tests were made at 850 and 1500 volts, using the lower voltage for the higher currents. Comparative collection tests were made at 850 and 1500 volts under identical conditions which clearly indicated that the voltage of contact line makes no difference in the collection of current so long as the voltage is more than adequate to maintain any arc that might occur between contact wire and pantograph.

Tests were also made to approximate conditions existing under prolonged acceleration periods, and to determine the temperature rise in various members of the contact system and in the collector.

With each change in contact wire arrangement and suspension, tests were started with low current values and at low speed and gradually worked up to maximum allowable values. A number of duplicate runs was made at maximum values to check the final results.

## Testing Equipment

*A. Power Supply.* Current was obtained from the substation used to supply power to the test track. Power was supplied to the overhead line through a 1,000,000-cir. mil feeder shown in Fig. 15.

*B. Test Train.* A special test train was assembled consisting of a 110-ton gearless locomotive capable of operating at speeds up to 70 mi. per hr. with either 600 or 1500 volts. This locomotive was coupled to a special gondola car followed by a standard passenger car used as an observation car equipped with ammeter, speedometer and telephone, Fig. 2. These cars were furnished by the New York Central Railroad. As the weight of this train was not sufficient to give the current desired, a sufficient number of iron grid rheostats with contactors and switches arranged to give the additional current required for the tests was assembled in the gondola car. By means of this equipment, it was possible to obtain any load up to 6000 amperes at 850 volts and 4500 amperes at 1500 volts. It was also possible to obtain load at 3000 volts although only a few runs were made at this voltage. The two pantographs were installed 57 ft. apart which was considered representative spacing for a two-unit locomotive.

*C. Track.* The track used for general testing is 4.15 mi. in length and is laid with 100-lb. rail in slag ballast.

Of this total length, about two miles were used for high speed running, while testing and demonstrating. The remainder was used for acceleration and retardation.

*D. Observation Towers.* It was decided to make the unusual provision of observation towers in addition to the observation car referred to elsewhere.

There were five towers with platforms capable of accommodating from 12 to 15 people, located at a height placing the eyes of the average observer slightly higher than contact wires and collector shoes, and providing an unobstructed view of all the parts entering into current collection, when approaching, passing and leaving. Towers were located as close to track as permitted by clearance requirements.

An added feature in this connection was that studies were made at night when the slightest spark between wire and shoe could be detected from these points of vantage.

*E. Overhead Contact System.*

*1. General Design of Contact System.* On account of the heavy current values contemplated, it was thought advisable to shorten and simplify the taps between feeder and contact wires as much as possible, and to

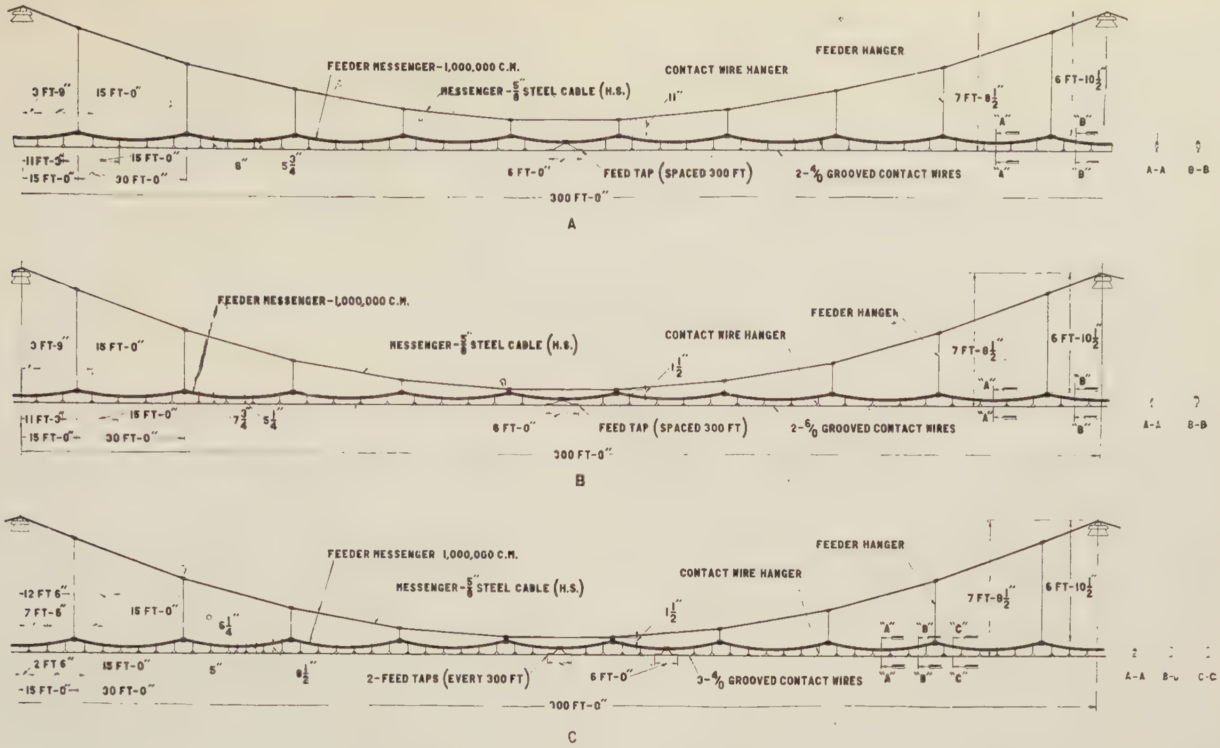


Fig. 4—Loop-Hanger Suspension

reconstruct with compound catenary, suspending the feeder from the messenger and the contact wires from this feeder messenger. With the length of span adopted, 300 ft., ⅝-in. high-strength steel cable was selected for the messenger.

The feeder messenger was suspended from the messenger by means of hangers made of No. 2 A. W. G.

Fig. 5—Loop-Hanger Suspension With 2-4/0 Contact Wires

solid, hard-drawn copper, with bronze clamps for attachment to messenger and feeder messenger.

*2. Contact Wire Arrangements and Suspension.* The first installation included several arrangements of contact wires and methods of suspension as described below and referred to on Fig. 1. The table on this drawing gives the final arrangement.

a. Between points 1 and 2, 3600 ft. Two 4/0 wires, loop-hanger, suspension, (A), Fig. 4. Also Fig. 5.

b. Between points 2 and 3, 600 ft. Two 4/0 wires, laced suspension, (A) and (B), Fig. 6. Also Fig. 7.

c. Between points 3 and 4, 1200 ft. Two 6/0 wires, loop-hanger suspension, (B), Fig. 4.

d. Between points 4 and 5, 1200 ft. Three 4/0 wires, loop-hanger suspension, (C), Fig. 4. Also Fig. 8.

e. Between points 5 and 6, clamp suspension, 600 ft., Fig. 10.

f. Between points 6 and 7, 2400 ft. Two 4/0 wires, loop-hanger suspension, (A), Fig. 4. Also Fig. 5.

Short sections of two additional types of contact wire suspension were installed during preliminary tests.

g. Cable-hanger suspension, reproduction of photograph, Fig. 11.

h. Twin laced suspension with which the two contact wires were suspended by independent lacings from symmetrical yokes attached to the feeder messenger, locating them about 3½ in. apart and in the same horizontal plane.

*3. Feed Taps.* Loop-hanger suspension, (a) and (f), required feed tap connections, Fig. 12, which were installed at the center of each span, or 300 ft. apart. The feed tap cable was of 4/0 copper with 19 wires.

*4. Reasons for Several Contact Wire Arrangements.* The selection of two contact wires in the same horizontal plane was due to previous experiments and actual experience on the Chicago, Milwaukee & St. Paul Railway and other lines, where current collected was of considerable value. The main virtue of this arrangement, in addition to the increased contact surface, is that with alternate or staggered suspension of the two wires, the collector shoe is always in contact

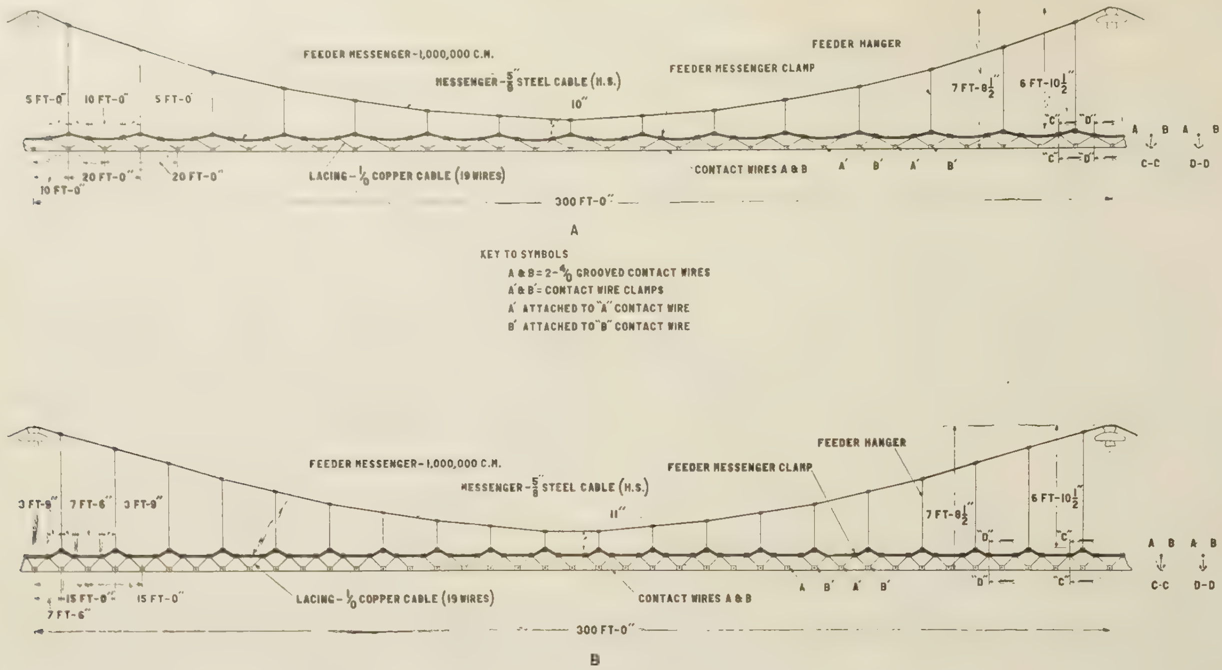


Fig. 6—Laced Suspension

with two wires, and one wire is always without any additional weight due to hangers or other fittings.

The installation of two 6/0 wires was made to get information as to the handling and performance of this size wire as a contact member: First, on account of its having been proposed by several foreign engineers; second, to try out this method of increasing cross-section should the two 4/0 wires show undesirable temperature

Fig. 7—Laced Suspension (Outside Rail for Testing Wide Gauge Locomotives)

rise; third, to study the effect of the additional weight in contact wires.

The installation of three 4/0 wires was made in line with possible need for more cross-section and more contact and to get experience in connection with their use, including the additional weight.

## Methods of Making Tests and Basis for Conclusions

With the several types of contact wire arrangement and suspension in place, for any given set of test runs, the remaining fixed factor was line voltage. Those subject to change were speed, amount of current collected, number of pantographs, and pantograph pressure.

Observation tower construction and location permitted direct comparison between the performance of the several types of overhead construction with a certain line voltage and any desired combination of the variables.

Independent and simultaneous observations were made by four or five individuals from the same tower,

Fig. 8—Loop-Hanger Suspension With 2-4/0 Contact Wires

and such observations made from several towers for each principal condition, so as to cover different types of construction and track alinement.

It was decided that collection would be deemed satisfactory if, at night, it appeared sparkless to an observer looking down on top of the collector shoes.

## Results of Experiments with Contact Wire Suspension

*General.* The original layout contemplated the general use of loop-hanger suspension (a), (c), (d), and (f), and the short section of clamp suspension (e).

During the early stages of the test runs, short sections of laced suspension (b) and cable-hanger suspension (g) were installed and compared with loop-hanger and clamp suspension, with the results given below.

*1. Loop Hangers (a) and (f).* This type of suspension was selected for the larger portion of the work on account of flexibility and because it was being successfully used when currents of considerable magnitude were encountered, in regular service, though smaller in value than the heavy currents contemplated in this case.

Fig. 10—Clamp Suspension

Fig. 11—Cable-Hanger Suspension

With the general construction used for these tests, loop hangers, with feed taps spread 300 ft. apart, provided the necessary conductivity between feeder messenger and contact wires for current values not in excess of 2500 amperes.

The Chicago, Milwaukee & St. Paul Railway, using simple catenary construction with loop hangers, steel messenger, and two 4/0 A. W. G. copper contact wires in the same horizontal plane, during an operating period of 11 years and a total of 650 route mi. has had about three interruptions on account of messenger being burned at loop hangers.

These cases were all due to defective feed tap clamps at contact wire shunting the current through the steel messenger. General replacement of these clamps was made with an improved design and no further trouble of this kind has been experienced. Other roads equipped with the improved clamp have not experienced this trouble.

*2. Laced Suspension (b).* This method of suspension offered flexibility in line with that of loop hangers and the added feature of very frequent taps to feeder messenger and cross taps between contact wires. The first trial was made with two feeder hanger spacings, 30 ft. and 15 ft., with a minimum distance of six inch between top of contact wires and under side of feeder messenger. A few test runs indicated that the section with shorter hanger spacing gave better collection. Comparison with other types of suspension tested brought about the conclusion that the laced suspension provided the best conductivity between feeder and contact wires for the collection of the amount of current contemplated, and it was therefore adopted for further test runs and demonstrations.

Fig. 12—Feed Tap With Loop-Hanger Suspension

*3. Clamp Suspension (e).* This design possessed the following features: Direct connection between contact wires and feeder messenger, the use of clamps instead of more expensive hangers or clamps and lacing, and the possibility of operating contact wires at comparatively low tension. After a few test runs, this design was dismissed from further consideration for the purpose in hand. With two contact wires, the lift was such that pantograph shoes struck feeder messenger clamps. While an increased number of wires would tend to reduce the lift, the complication accompanying additional wires and the fact that one shoe would, with any number of wires, make contact with one wire only throughout a great part of the line, did not encourage further investigation at that time.

*4. Cable Hanger Suspension (g).* About 150 ft. of line was equipped with these hangers, spaced 15 ft. apart or 30 ft. on each contact wire. For test purposes, hangers were made of 1/0 B&S flexible copper strand, and the contact wire clamps used with laced suspension.

Attachment to feeder messenger was made by copper wire wrapping.

This suspension approached laced construction in general principle and provided a manufactured unit, permitting attachment of clamps to strand by welding or other means supposedly preferable to clamped connection. This suspension showed no improvement over the simpler laced construction and the design was therefore eliminated.

5. *Twin Laced Suspension* (*h*). The trial of this suspension, incidental to collection trouble with laced suspension on a one-deg. curve, was made during the early stages of the tests. The design was never given serious consideration on account of inherent faults, including expense of two lacings and the special yokes for attachment to feeder messenger, which would be expensive and difficult to maintain in any desired plane.

## Results of Experiments with Contact Wire Arrangements

Shortly before the completion of test runs and the demonstration of current collection, it was decided that two 4/0 contact wires in the same horizontal plane with proper suspension and tension provided the necessary cross-section, contact surface, and weight for current collection covered by the tests.

While the experience gained with 6/0 contact wire was limited to a very small quantity, the condition of the wire as installed was never satisfactory owing to long kinks, presumably due to winding on reel. While this trouble may be avoided by using a reel with proper drum diameter, the general impression was that wire of this size should be passed through a wire straightener mounted on tower car, as it is strung. As stated above, there seems to be no reason for adopting this special and undesirable size of wire.

While no particular trouble was encountered in connection with the three 4/0 contact wires, there was no indication of the additional wire being required, and its use would certainly complicate the contact system and introduce the undesirable requirement of maintaining approximately even tension in three wires instead of two, in order to get the best results.

The following data apply to contact system finally used for tests and demonstrations:

| Member | Material | Size | Wt. lin. ft. pounds |
|---|---|---|---|
| Messenger | H. S. Steel | 5/8 in. | 0.8 |
| Feeder Messenger | Copper | 1,000,000 cir. mils | 3.1 |
| Feeder Messenger | Copper | 750,000 " " | 2.325 |
| Lacing | Copper | 105,000 " " | 0.322 |
| Contact wire 1 | Copper | 211,600 " " | 0.64 |
| Contact wire 2 | Copper | 211,600 " " | 0.64 |

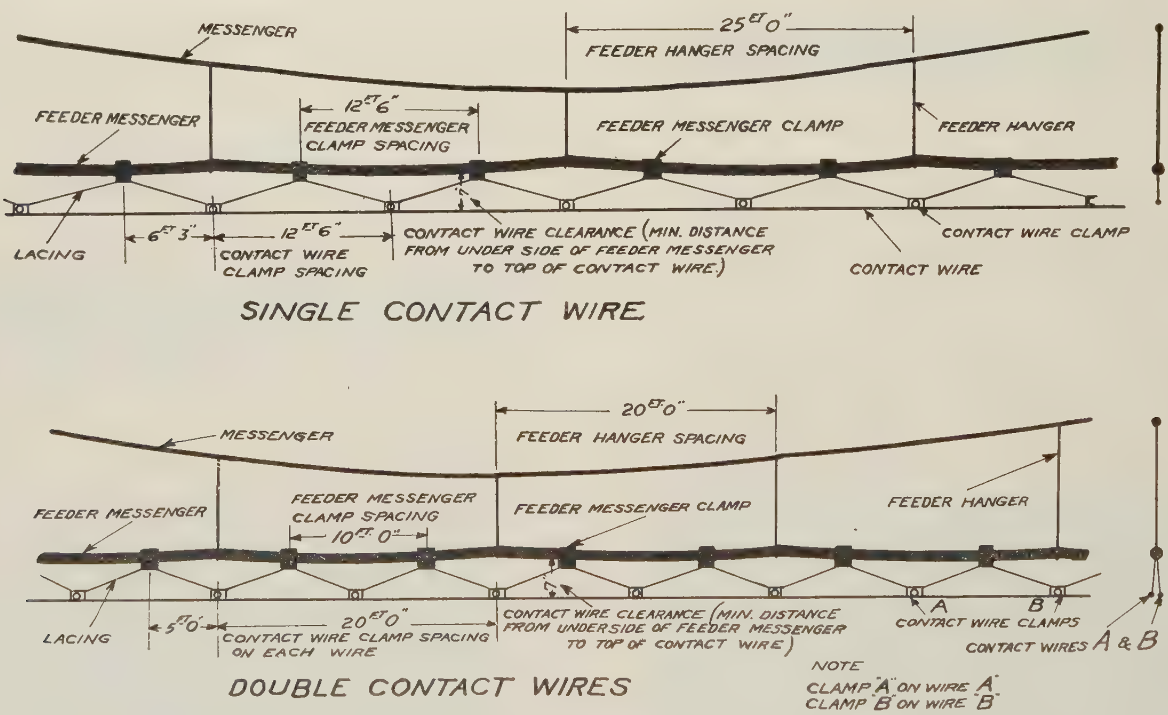


Fig. 13—Catenary Construction Laced Suspension for Contact Wires (Final Recommendations)

After completion of tests, it was decided that the arrangement with laced suspension for single and double contact wires should be as shown on Fig. 13.

## Contact System on Curves

All curve work in the original installation was fitted with loop-hanger suspension for contact wires, and both feeder and contact wire hangers were inclined as shown in Fig. 14. This illustration also shows feeder connection at substation, consisting of one 1,000,000-cir. mil cable, which supplied current to line for all tests including heat runs.

Current collection on this curve construction, as experimentally installed in combination with other factors affecting current collection, was not satisfactory on account of arcing. Laced suspension with inclined messenger gave the same results. No further studies were made with inclined hangers but contact system was trimmed in chords with pull-offs located 150 ft. apart, as shown in Fig. 15.

The final combination of laced and chord construction gave practically sparkless current collection.

### Contact Wire Tension

As originally installed, contact wires had a tension of 1000 lb. at 70 deg. fahr. Before tests were completed, this tension was considerably below that value due to seasonal increase in temperature and many changes made in line construction. When curve work

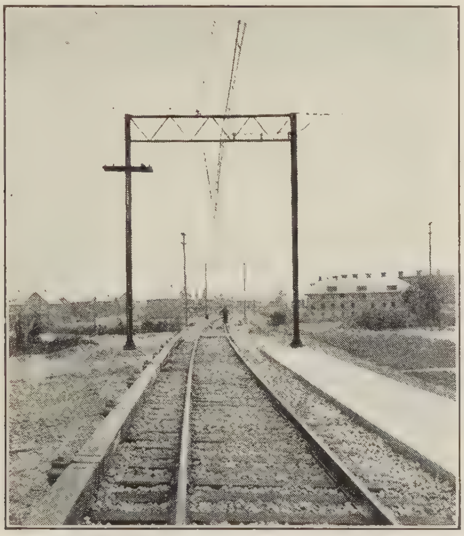

Fig. 14—Loop-Hanger Suspension on Curve

Showing inclined messenger construction

was finally adjusted late in June, tension was increased to from 1300 lb. to 1400 lb. at 70 deg. fahr. and with improved collection throughout.

### Collectors

The collector used throughout for test runs and demonstrations was the S-501-A slider trolley with certain modifications mentioned later, (Fig. 16).

The collector consists of two flexibly mounted contact shoes on top of a jointed diamond or pantograph frame, the diamond or pantograph frame being constructed of Shelby tubing with malleable iron joint castings so hinged together that it can readily expand or contract to suit variations in height of contact wires.

The small irregularities in the overhead are taken care of by the flexibility of the contact shoes. Each shoe is independently hinged on two spring supported cams which allow it to rise and lower two inches independent of the main or diamond frame. The contact shoes are composed of sheet steel pans with sheet steel horns attached to each end for picking up the siding wires. The wearing strips are of hard drawn copper, 3/16 in. thick and 1-3/16 in. wide, having one edge bent over slightly to prevent fouling, leaving approximately ¾ in. of width, flat surface. The space between the renewable, wearing strips is filled with a lubricant for preventing a rapid deterioration of both strips and contact wire.

The standard collector has a rated continuous capacity of 1000 amperes, or 2000 amperes for two min., and is suitable for speeds up to 60 mi. per hr.

Fig. 15—Laced-Type Suspension on Curve

Showing chord construction and feeder connection

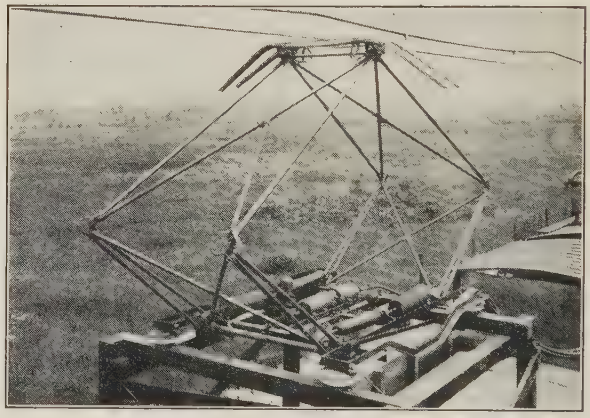

Fig. 16—S-501-A Pantograph Used for Current Collection Tests

As mounted on wooden structure in the Gondola carrying the grids

In order to bring the capacity up to the heavy current requirements, the collectors were fitted with additional shunts around each bearing and a flat copper strip along one side of both top and bottom frame arms. The additional weight imposed by this copper necessitated increasing capacity of balancing springs.

As far as principle of design goes, a standard collector was used and the only special precaution taken was to surface the wearing strips on an emery-covered face plate after assembly, which should be done in regular practise regardless of current values.

### Collector Pressure

During testing period, collector pressures varying between 19 and 43 lb. were used. Reference to list of test runs shows that the pressure finally used for the collector and contact system dealt with was about 40 lb. This pressure was necessary on account of the increased moving weight due to copper shunts and strips.

### Current Collection Tests

The following list gives data on a group of representative test runs with both 850 and 1500 volts, using the type of contact system finally adopted. More than 350 test runs were made and records kept in connection with all runs.

TESTS AT 850 AND 1500 VOLTS

| Test no. | Amps. | Speed mi.perhr. | Volts | No. of collectors used | Pressure lbs. | Date |
|---|---|---|---|---|---|---|
| 125 | 5000 | 50 | 850 | 1 | 32.5 | 6–15–23 |
| 150 | 5000 | 50 | 850 | 1 | 30 | 6–19–23 |
| 160 | 6000 | 50 | 850 | 2 | 35 33 | 6–23–23 |
| 161 | 6000 | 50 | 850 | 2 | 35 33 | 6–23–23 |
| 162 | 6000 | 50 | 850 | 2 | 35 33 | 6–23–23 |
| 164 | 5100 | 50 | 850 | 2 | 35 33 | 6–23–23 |
| 172 | 5200 | 54 | 850 | 2 | 35 37 | 6–24–23 |
| 173 | 5200 | 54 | 850 | 2 | 35 37 | 6–24–23 |
| 224 | 5100 | 65 | 850 | 1 | 37.5 | 6–28–23 |
| 225 | 5000 | 60 | 850 | 1 | 37.5 | 6–28–23 |
| 227 | 5100 | 60 | 850 | 1 | 37.5 | 6–28–23 |
| 232 | 5200 | 50 | 850 | 2 | 39 40.5 | 7–10–23 |
| 240 | 5000 | 50 | 850 | 1 | 40.5 | 7–11–23 |
| 244 | 5000 | 55 | 850 | 1 | 40.5 | 7–12–23 |
| 249 | 5300 | 57 | 850 | 1 | 40.5 | 7–13–23 |
| 250 | 5400 | 56 | 850 | 2 | 40.5 42 | 7–13–23 |
| 254 | 5300 | 57 | 850 | 1 | 39.5 | 7–13–23 |
| 255 | 5300 | 58 | 850 | 1 | 39.5 | 7–13–23 |
| 256 | 5800 | 53 | 850 | 2 | 39.5 42 | 7–13–23 |
| 257 | 5800 | 55 | 850 | 2 | 39.5 42 | 7–13–23 |
| 278 | 5500 | 58 | 850 | 2 | 34.5 | 7–16–23 |
| 280 | 5400 | 58 | 850 | 1 | 34.5 | 7–16–23 |
| 96 | 4300 | 32 | 1500 | 2 | 32.5 34.5 | 6– 4–23 |
| 110 | 4000 | 52 | 1500 | 2 | 32.5 34.5 | 6–15–23 |
| 191 | 4200 | 48 | 1500 | 2 | 39 40.5 | 6–26–23 |
| 192 | 4000 | 48 | 1500 | 2 | 39 40.5 | 6–26–23 |
| 198 | 4500 | 40 | 1500 | 1 | 39 | 6–26–23 |
| 200 | 3000 | 60 | 1500 | 1 | 39 | 6–26–23 |
| 259 | 4500 | 46 | 1500 | 1 | 39.5 | 7–14–23 |
| 261 | 4150 | 48 | 1500 | 1 | 39.5 | 7–14–23 |
| 281 | 4500 | 50 | 1500 | 1 | 39.5 | 7–17–23 |
| 282 | 4600 | 52 | 1500 | 1 | 39.5 | 7–17–23 |

### Temperature Tests

Temperature tests were made to determine heating of the contact wire, feeder, messenger, pantograph shoe, etc., in order to definitely establish that it is possible to conduct heavy currents to a locomotive. These tests were made on the laced overhead trolley construction as shown in Fig. 7. The feeder in this section is a 1,000,000-cir. mil copper conductor acting as a messenger.

Test No. 1: This test was made with both pantographs raised and current maintained at approximately 5200 amperes for five minutes. Nine readings were taken at one-min. intervals, the first five being taken while current was flowing and the last four after the circuit was interrupted. A maximum temperature rise of 67 deg. cent. was obtained on the contact wire near pantograph 2, lacing 23.

Test No. 2: This test was made with one pantograph located near lacing 23 with approximately 5200 amperes for five minutes. Ten readings were taken, five while current was flowing and five after interruption of the circuit. A maximum temperature rise of 101 deg. cent. was obtained on the contact wire near the pantograph.

TEST NO. 1

5200 Amperes for Approximately Five Minutes, Two Pantographs. Maximum Temperature Rise, Deg. Cent.

| Thermometer location | at Pantograph | | Distance from Pantograph No. 1 | | | | |
|---|---|---|---|---|---|---|---|
| | No. 1 | No. 2 | 127.5 ft. | 150 ft. | 195 ft. | 217½ ft. | 15 ft.* |
| Feeder | 4 | 28 | 27.2 | 30 | 27.5 | 27 | 1.0 |
| Lacing | 12 | 33 | 13.5 | 13.5 | 14.5 | 13 | .. |
| Contact wire | 35 | 67 | 31.0 | 28.4 | 29.0 | 21 | 4.2 |
| Shoes | 10 | 17 | .. | .. | .. | .. | .. |

Temperature of air, 25 deg. cent.

TEST NO. 2

5200 Amperes for Approximately Five Minutes, One Pantograph. Maximum Temperature Rise, Deg. Cent.

| Thermometer location | at Pantograph | | Distance from Pantograph No. 1 | | | | |
|---|---|---|---|---|---|---|---|
| | No. 1 | No. 2 | 127.5 ft. | 150 ft. | 195 ft. | 217½ ft. | 15 ft.* |
| Feeder | 29 | 40.5 | 31 | 30 | 28.5 | 28.0 | 115 |
| Lacing | 55 | 18.0 | 16.0 | 15.6 | 16.0 | 14 | .. |
| Contact wire | 101 | 36.0 | 28 | 29.2 | 30.5 | 23.5 | 27 |
| Shoes | 53 | .. | .. | .. | | | |

Temperature of air, 25 deg. cent.

*Thermometer location on opposite side from source of power.

These tests do not reproduce exact operating conditions after a train has started but might apply while locomotive is standing still, attempting to start a train. The temperatures obtained are so low and the current and time used in the tests so high that they clearly indicate that no trouble would be experienced due to overheating of the distributing, contact, or collecting equipment.

### Burn-Off Tests

These tests were made to determine the amount of burning which would be obtained if a pantograph should start to drop while carrying heavy currents and for some reason was checked and held in position a few inches from the contact wire. These tests were made with the locomotive standing still. While different amounts of currents were passing through the contact wire and pantograph, the pantograph was released, stopped and held. Potential of 1500 volts was held on the contact wire throughout the tests. Twenty tests of this kind were made with current reaching a maximum of 4400 amperes, the maximum drop of the pantograph being 17 in. and the minimum one inch. In no case was the contact wire or pantograph seriously damaged. A pantograph was also dropped without checking with 5000 amperes at 850 volts, without serious damage.

Several tests were made interrupting 4000 amperes

1500 volts with locomotive control arranged so that if the pantograph should begin to drop due to low air pressure, a pressure relay on the locomotive would open the main breaker and interrupt the circuit. With this system of control, there was no sparking at pantographs.

## Conclusions

*Contact System Design.* Contact systems in actual use for heavy traction vary in principle of design between direct suspension with considerable weight concentrated at points of contact wire support, and catenary suspension with practically no change in contact wire weight and freedom of vertical movement throughout. There is a corresponding variation in current transfer capacity.

It is desirable to provide a contact member of uniform flexibility, and, so far as possible, of uniform weight throughout. The necessity for flexibility and uniformity in weight increases as current values increase.

It is important to avoid the use of fittings which obstruct in any way the contact between contact wire and pantograph shoes.

*Contact Wire Lubrication.* Experience gained by these tests and on lines equipped with the same or similar type of pantograph shows that a very thin film of lubricant should be maintained on under side of contact wire and that there is no difficulty in this connection provided pantograph shoes are properly lubricated.

It is interesting to note that contact resistance between wire and shoe is decreased when lubricant is used. This is probably due to elimination of chattering and actual glazing of contact wire and wearing strips of pantograph shoes.

*Contact Wire Tension.* Contact wire tension should be maintained at the highest value consistent with temperature conditions and other limiting features.

*Current Collector Design.* The efficiency of this device is affected by the following details:

Weight of moving parts and friction in bearings and joints which may interfere with its response to any change in contact wire height,

Design of contact shoe, including number and assembly of wearing strips, lubrication and facilities for lubrication,

When two shoes are used, the degree of independence of movement and spring control,

The rigidity of pantograph frame in connection with side sway,

It is to be noted that a collector of standard design, with slight modifications to increase current carrying capacity, was used throughout these tests.

*Shoe Pressure.* The word "pressure" is intended to mean the pressure exerted at standard contact wire height with pantograph in motion or with friction practically eliminated. This value can be obtained by tying the pantograph with the shoe at standard contact wire height and reading pressure with spring balance while pantograph is shaken, thus approximating the condition while collecting.

It is desirable to emphasize the importance of pressure in connection with current collection, and, when more than one collector is used, the equalization of pressure.

Shoe pressure must be adapted to the overhead contact system design and should be maintained at the minimum value found practicable in each case.

*Number of Collectors Used and their Spacing.* These items determine the total upward pressure on contact wires and distribution of pressure, and certain combinations may disqualify a contact system suitable for use with a single collector or other combinations.

The number of collectors used must be determined by their design, current to be collected, and their minimum spacing, by overhead contact system design outside of locomotive design and other considerations. It is desirable to make this distance a maximum.

*Speed.* The speed at which a collector is moved introduces the effects of wind pressure on pantograph frame and certain parts, such as shoe horns, the inertia of pantograph frame and shoes, and side whipping with bad track surface. It also places limits on grades in contact wire and changes in weight and flexibility of contact wire.

*Effect of Voltage on Current Collection.* Test runs were made with 750, 850 and 1500 volts. With all other conditions the same, no difference could be detected in quality of current collection with the three voltages mentioned.

*General.* Conservative evaluation of these tests and experience gained from operated lines indicate that 2000 amperes or more can be successfully collected, at any speed up to 60 or 70 mi. per hour, with one pantograph, and 4000 amperes with two pantographs.

These tests also demonstrate that it is practicable to design and construct an overhead contact and distribution system capable of delivering more than the amount of current required for train propulsion with line potentials used to date for trunk line electrification.

The type of suspension connecting messenger or feeder messenger and contact wire or wires and its conductivity must be governed by the maximum current to be collected.

These tests and experience lead to the following approximate ratings for the types of construction given:

a. Steel messenger, two 4/0 copper contact wires, loop hangers, feed taps spaced 1000 ft., as used on Chicago, Milwaukee & St. Paul Railway:

Normal current, 1000 amperes with a maximum of 1500.

b. Compound catenary with auxiliary feeder, messenger, loop hangers and feed taps spaced 300 ft.

Normal current 2000 amperes with a maximum of 2700.

c. For higher current value, the frequencies of feeder taps must be increased in proportion to the current demand.

# Two Cases of Calculation of Mechanical Forces in Electric Circuits

BY H. B. DWIGHT[1]

Fellow, A. I. E. E.

*Synopsis.—A formula is derived for the mechanical force in a circle of round wire, due to its own current. A formula,* $F = I^2 \operatorname{logh} \frac{a_1}{a_2}$, *is also derived for the longitudinal force exerted on a round conductor, due to its own current, where it changes its diameter. Where there is a constriction in a liquid conductor, this force acts in both directions away from the constriction, thus tending to accentuate it. It may be that this has more to do with the rupturing of a liquid conductor by heavy current, than the better known forces acting in a radial direction, which have been usually referred to under the name "pinch effect."*

THE measurement by a laboratory method of mechanical force in circular and rectangular circuits, described in a companion paper by Mr. J. W. Roper[2], lends interest to formulas for calculating such forces. In this paper, formulas are presented for the force acting in a circular circuit and also for the axial force acting in a straight cylindrical conductor where the size of the cross-section changes.

## Force in a Wire Circle

The force tending to stretch the wire in a circular circuit is calculated by the well-known method using the differential of the self-inductance of the circuit. The mutual inductance of two coaxial circular filaments is given with a great deal of precision by formulas involving elliptic integrals or by convergent series. Rayleigh and Niven have integrated the expression for this quantity over a circular cross-section, giving the self-inductance of a circle of round wire. Their formula is[3]

$$L = 4\pi a \left[ \operatorname{logh} \frac{8a}{\rho} - \frac{7}{4} + \frac{\rho^2}{a^2}\left( \frac{1}{8} \operatorname{logh} \frac{8a}{\rho} + \frac{1}{24} \right) \ldots \right] \text{abhenrys} \quad (1)$$

where $a$ is the radius of the circle and $\rho$ is the radius of the wire. The expression logh denotes the hyperbolic or natural logarithm.

When current flows in a circle of wire, one half tends to repel the other half, and a tendency to stretch the wire is exerted at every part of the length of the wire. Let this force be $F$ dynes and let $s$ be the perimeter of the circle. If the current is turned on, and the force $F$ stretches the wire a distance $\partial s$, the mechanical work done is $F\,\partial s$, since $F$ acts in the direction of $s$. This can be equated to $\frac{1}{2} I^2 \partial L$ where $\partial L$ is the change in the self-inductance of the circle due to its change in size.

This rather well-known expression can be derived as follows:

The rate of doing mechanical work is $F \frac{\partial s}{\partial t}$. Since the current $I$ is kept constant and the inductance $L$ is varying, a voltage is generated in the circle equal to $I \frac{\partial L}{\partial t}$ and the current $I$ flowing against this voltage supplies energy at the rate $I^2 \frac{\partial L}{\partial t}$. This energy goes to supply the mechanical work and also to increase the stored energy of the magnetic field. The stored energy is $\frac{1}{2} L I^2$ for inductance[4] equal to $L$. The rate of change of the stored energy when $I$ is constant and $L$ varies is $\frac{1}{2} I^2 \frac{\partial L}{\partial t}$.

Therefore,

$$I^2 \frac{\partial L}{\partial t} = F \frac{\partial s}{\partial t} + \frac{1}{2} I^2 \frac{\partial L}{\partial t}$$

Then

$$F\,\partial s = \frac{1}{2} I^2 \partial L$$

and

$$F = \frac{1}{2} I^2 \frac{\partial L}{\partial s} \quad (2)$$

This force is in dynes since absolute units are used throughout.

1. Professor of Electrical Machinery, Massachusetts Institute of Technology.

2. J. W. Roper, *Experimental Measurement of Mechanical Forces in Electric Circuits, Jl. A. I. E. E., Sept. 1927, p. 913.*

3. Equation 63, Scientific Paper No. 169 of the Bureau of Standards, 1911, and Rayleigh's collected papers, Vol. II, p. 15.

*Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Pittsfield, Mass., May 25-28, 1927.*

4. Principles of Alternating Currents, by R. R. Lawrence, p. 124, equation (14).

The dimension $s$ is the circumference of the circle and is equal to $2\pi a$.

Therefore

$$F = \frac{1}{4\pi} I^2 \frac{\partial L}{\partial a} \tag{3}$$

The differentiation of Rayleigh and Niven's formula (1) is quite straightforward and the following formula for force is obtained:

$$\frac{F}{I^2} = \text{logh}\,\frac{8a}{\rho} - \frac{3}{4} - \frac{\rho^2}{a^2}\left(\frac{1}{8}\,\text{logh}\,\frac{8a}{\rho} - \frac{1}{12}\right)\cdots \quad \text{dynes} \tag{4}$$

where $I$ is the current in abamperes.

*Example 1.* The force in a wire of radius $\rho = 0.1245$ cm. bent into a circle of $a = 20.1$ cm. radius and carrying 100 amperes is

$$10^2\left[\text{logh}\,\frac{8 \times 20.1}{0.1245} - 0.75 - \frac{0.1245^2}{20.1^2}\left(\frac{1}{8}\,\text{logh}\,\frac{8 \times 20.1}{0.1245} - \frac{1}{12}\right)\right]$$

= 641 dynes. (See the calculated curve of Fig. 2 of Mr. Roper's paper).

## Longitudinal Force

The following short formula gives the amount of the longitudinal force; that is, the force acting in the direction of the axis, which is exerted on a round conductor where it changes its diameter:

$$F = I^2\,\text{logh}\,\frac{a_1}{a_2} \quad \text{dynes} \tag{5}$$

where $a_1$ and $a_2$ are the larger and smaller radii, respectively, and where $I$ is the current in abamperes.

The force acts parallel to the axis and toward the larger section of conductor, irrespective of the direction of flow of current. The expression involves only the maximum and minimum radii and, as referred to later, the amount of the force is independent of the shape of the conductor while it is changing section, so long as it is round and centered on a straight axis.

Formula (5) is useful in calculating the force on a system of round wires in air where there are wires of more than one diameter. It is also of interest in connection with some kinds of electric furnaces where a trough of molten metal carries a heavy electric current. If there is a constriction in the section of the metal, this force produces a flow of metal away from the constriction and so accentuates the constriction. Such an action has been observed.

As is well known, electromagnetic forces also act on all elements of a liquid conductor at right angles to the direction of current flow; that is, in general, toward the axis. This produces greater hydrostatic pressure at the axis than in the outer parts, and, of course, hydrostatic pressure acts equally in all directions.

The hydrostatic pressure in a uniform round conductor, which acts in a radial direction, has been referred to for a number of years under the name, "pinch effect." It has been described as the cause of the phenomenon observed in electric furnaces, that at a certain heavy current a constriction would occur in the liquid conductor, and that this constriction would grow until the circuit was broken.

It is possible that the axial force described and calculated in this paper, which tends to separate the two tapered parts where a constriction occurs in a liquid conductor, is more directly connected with rupturing the conductor at the point of constriction than the radial "pinch effect" force.

The axial force is stronger in the outer parts of the tapered conductor than in the inner parts. In the case of a liquid conductor, unequal forces acting on different parts produce a flow of the liquid, sometimes in short return paths, like local eddies. The amount of this flow

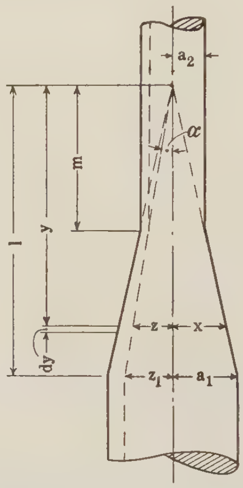


Fig. 1—Conductor with Change in Section

depends on the strength of the electric current and the shape and viscosity of the liquid conductor.

Equation (5) is derived by the method of finding the product of the strength of a current and the magnetic field in which it lies, to give the force on the conductor carrying the current.

Assume that the current density is uniform over any cross-section of the wire shown in Fig. 1. Slight departures from this assumption take place where the stream lines do not have abrupt changes in direction, but follow smooth curves. Skin effect also is not considered. The current density at distance $y$ where the radius is $x$ is

$$i = \frac{I}{\pi x^2}$$

The total current inside radius $z$ is

$$\pi i z^2 = I\,\frac{z^2}{x^2}$$

The flux density at radius $z$ is

$$\frac{2}{z} \cdot \frac{I z^2}{x^2} = \frac{2I}{z} \frac{z_1^2}{a_1^2}$$

The dotted line at radius $z$ is always at the proportionate distance $\frac{z_1}{a_1}$ along the radius of the wire, and it is almost exactly a line of current flow. A short element of it has a length $\frac{dy}{\cos\alpha}$

where

$$\tan\alpha = \frac{z_1}{l} = \frac{z}{y} \qquad (6)$$

A force acts on the short element of the filament carrying current at right angles to its length and proportionate to the current in the filament and the magnetic field in which it lies. This force is

$\frac{2I}{z} \frac{z_1^2}{a_1^2} \frac{dy}{\cos\alpha}$ dynes per abampere of current in the filament.

Multiply by $\sin\alpha$ to get the component of force parallel to the axis:

$$\frac{2I}{z} \frac{z_1^2}{a_1^2} \tan\alpha \, dy = 2I \frac{z_1^2}{a_1^2} \frac{dy}{y} \text{ from } (6)$$

Integrate this from $y = m$ to $y = l$. The total force parallel to the axis acting on the filament is

$2I \frac{z_1^2}{a_1^2} \operatorname{logh} \frac{l}{m}$ dynes per abampere of current in the filament. (7)

If the filament be considered to have a thickness $dz_1$ at the radius $z_1$ then the total area of all filaments at radius $z_1$ is

$$2\pi z_1 \, dz_1$$

and the total current in them is

$$\frac{I}{\pi a_1^2} 2\pi z_1 \, dz_1 = \frac{2I}{a_1^2} z_1 \, dz_1$$

The force parallel to the axis acting on the above current is, by (7),

$$2I \frac{z_1^2}{a_1^2} \left(\operatorname{logh} \frac{l}{m}\right) \frac{2I}{a_1^2} z_1 \, dz_1$$

Integrate this from $z_1 = 0$ to $z_1 = a_1$.
The total force parallel to the axis is

$$I^2 \operatorname{logh} \frac{l}{m}$$

$$= I^2 \operatorname{logh} \frac{a_1}{a_2} \text{ which is equation (5).}$$

If the wire tapers from a radius $a_1$ to a radius $a_m$, the axial force due to that part will be

$$I^2 \operatorname{logh} \frac{a_1}{a_m}$$

If the wire then tapers at a different rate from radius $a_m$ to radius $a_2$, the force due to that part will be

$$I^2 \operatorname{logh} \frac{a_m}{a_2}$$

and the total force will be

$$I^2 \operatorname{logh} \frac{a_1}{a_2}$$

This is the same as if the wire had tapered uniformly from radius $a_1$ to $a_2$, as in Fig. 1. The change in radius can therefore be made by means of a large number of tapers of different angles, and the total axial force will depend only on the initial and final radii according to eq. (5).

In the above calculation, the value of the flux density at a radius $z$ is dependent on the total current $I_1$ within the circle of radius $z$. Since the wire is assumed to be straight and very long, and the return conductor so remote as to be negligible, the magnetic field lies in circles around the axis. The magnetomotive force around the circle of radius $z$ is $4\pi I_1$. The length of the magnetic path is $2\pi z$ and the flux density at radius $z$ is $\frac{2 I_1}{z}$. This formula, which is applicable to isolated long, straight, round wires, is seen to be true also when there are changes in section, provided the wire is symmetrical around a straight axis.

In calculating the magnetic field due to a short length of round wire carrying a current, it is often assumed that the field is the same as if all the current were flowing in a small filament at the axis of the round wire. While this is very nearly true, it is exactly true only in the case of an infinitely long wire, and this fact is sometimes of importance in calculations of inductance and of electromagnetic force. The expression for the field at a given point due to a short length of round wire involves elliptic integrals or series equivalent to them.

A case where the current cannot be assumed to be concentrated in a filament at the axis of a conductor is in finding the force on a conductor bent into a quadrant of a circle, for such an assumption makes the calculated force infinitely great. An expression for the force on a quadrant conductor due to its own current must involve the dimensions of the cross-section of the conductor.

The writer desires to make acknowledgment of the assistance of Mr. S. P. Sawyer in preparing numerical examples, etc., in connection with the work of this paper.

# Electrical Machinery

## Annual Report of the Committee on Electrical Machinery*

*To the Board of Directors*:

This committee has carried on its work during the past year according to the general plan of organization which has been in force for the past three years. The membership of the committee has been materially increased over the number of last year in an endeavor to be prepared to handle the increasing amount of work naturally resulting from the rapid growth in quantity, size, variety and quality of electrical machinery. Experience has shown that the work of a committee can be effectively carried on only when the members are able to get together and carry on a discussion across a table, following, perhaps, a preliminary exchange of views by letter. For this reason, the membership of the committee has been restricted to those living within a day's journey of New York or in the territory east of the Mississippi River. This territory embraces practically all of the manufacturers of electrical machinery, a large number of universities and large users of machinery for power generation and distribution. It is not intended, however, to exclude any members who are in a position to, or willing to, assist in any way whatsoever. In this connection, your attention is directed to the general call for volunteers which appeared on page 1 of the Journal of January, 1927, over the name of the chairman of this committee.

The committee has held two general meetings, one in October and one in February at the time of the Winter Convention. In addition to these, the various subcommittees have held meetings in connection with the work that has been assigned to them. In general, the subcommittees have reported progress of their work and presented opportunities for general discussion at the meetings of the whole committee.

The organization of this committee comprises subcommittees on (1) Standards, (2) Papers, (3) Research and (4) Education. It is probably not necessary to review here the functions of these subcommittees. Mr. E. C. Stone is chairman of the Standard Subcommittee, Prof. V. Karapetoff is chairman of the Research Subcommittee, Prof. C. A. Adams is chairman of the Education Subcommittee, while Mr. H. M. Hobart with the whole committee has acted as clearing house for receiving suggestions, obtaining and reviewing papers dealing with electrical machinery.

During the year, 15 papers have been presented under the auspices of this committee at the general meetings of the Institute. Turning to the developments in research as affecting the design of electrical machinery, probably the most important theoretical contributions have been in connection with the subject of the synchronizing power and stability characteristics of synchronous machines and the determination of the flux distribution in magnetic fields. In the field of design and manufacture, advances have been made in capacities of turbo generators, transformers, waterwheel-driven generators and synchronous condensers, there have been improvements in construction looking toward reductions of losses, the knowledge of the cooling and ventilation of machinery has been increased and definite steps have been taken to raise the operating characteristics of a-c. fractional horsepower motors to a higher level. In standardization, this committee has taken up a larger volume of work than ever before in the revision of existing A. I. E. E. Standards and the preparation of new Standards to keep pace with the continual development of improvements and new types of machinery and the necessity of changes arising from a better knowledge and understanding of the art. All of these additions to our knowledge and the improvements in design are chapters in the great story of the engineer's untiring efforts for the betterment of our social and economic status.

The following review has been prepared with the assistance and collaboration of the members of the committee and an attempt has been made to include the more important articles that have appeared in domestic and foreign journals in the several bibliographies. Undoubtedly, articles of real merit have been overlooked and the committee will welcome having such omissions brought to their attention.

### Research

Undoubtedly the most important phase of this committee's work is that which has to deal with the advancement of the art of design and manufacture of electrical machinery, through research. Without research, progress would be very slow. It is with a considerable degree of satisfaction that important contributions have been made during the year, both theoretical and experimental.

*Effect of Altitude on the Dielectric Strength of Insulations.* The committee has carried out some experiments to determine the relative puncture strengths of standard insulation at different atmospheric pressures. The results of these tests indicate that the reduction in the value of the voltage causing pucnture with decreased

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*Committee on Electrical Machinery:

H. M. Hobart, Chairman
J. C. Parker, Vice-Chairman
E. B. Paxton, Secretary

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| W. J. Foster, | A. M. MacCutcheon, | H. L. Zabriskie. |

*Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 20-24, 1927.*

atmospheric pressure is so small that no change in the A. I. E. E. Standards is considered desirable so far as insulated windings are concerned. When air is depended upon for insulation, however, a correction should be made for that part of the insulation which consists of air in series with solid insulation.

*Surge Tests of Insulation.* Work that has already been done indicates that the breakdown strength of solid insulation depends upon the kind and mode of test voltage and it does not seem feasible to specify for general use a test that will truly duplicate service conditions. A conventional test of the simplest kind will be just as satisfactory, provided the magnitude of the voltage is sufficiently high to provide a reasonable margin for the most unfavorable transient voltage liable to occur under actual service conditions. For example, if high-frequency oscillations are liable to take place and experimental data should show an ultimate strength of only 50 per cent as compared with 60-cycle voltage, then the magnitude of a 60-cycle test must be at least twice that of the maximum high-frequency oscillation to which the machine may be occasionally subjected in operation. In large machines designed to meet definite service conditions where the most unfavorable overvoltages are reasonably well known, the factor of safety may be chosen accordingly, but competitive considerations will largely govern the choice of insulation and its test for machines made in quantities for the general market.

It is recommended that designers study such data as are now available on this subject and that experimental assembled machines be tested by the different kinds of voltages for the purpose of obtaining data upon which may be based ratios for use in design and in specifications and guarantees.

*Hot Spots in Cores of Turbo Alternators.* Tests made by three manufacturers of typical American machines show that the temperature at the bottom of the slots at ends of the core is less than that between coil sides at the middle of the core and it is concluded that no change is needed in the present A. I. E. E. Standards as regards the location of temperature detectors.

*Evaluation of Conventional Losses.* Some work is being done to determine the feasibility of determining the stray load losses of alternators, synchronous motors and condensers by a more convenient means than those described in the Standards.

*Calorimetric Method of Determining Losses in Alternators.* Apparently this method requires such close supervision of detail and conditions that it may be considered more of a laboratory method than one which can be used for general commercial purposes. It is recognized, however, that this method has inherent possibilities for experimental work and is worthy of continued investigation. A paper giving results of extensive tests has been presented to the Institute during the year.

*Stability of Alternators.* A paper, *Stability Characteristics of Alternators,* has been presented by Mr. O. E. Shirley which showed the relation between stability and the short-circuit ratio and the subject has been referred to the Standards Subcommittee for the consideration of the establishment of a standard.

Some years ago it was the practise to design synchronous machinery with good inherent voltage regulation. With the advent of the vibrating voltage regulator, this practise changed since it was more economical to design machines with lower inherent voltage regulation and to depend on the voltage regulator to maintain voltage. This principle formed the basis of machine design until, in recent years, the work done on system stability indicated that for machines which were to be used on those systems where stability is an important consideration, a reversion to the former practise of designing for good inherent voltage regulation was desirable.

Recently, in the engineering of certain large power projects and extensions to existing systems, it has been decided to employ machines having lower leakage reactance and higher short-circuit ratio than machines of normal design for the same rating would have. The purpose of this is to increase the stability of the system upon which they are to be used and, in particular, to reduce the probability of system disturbances causing loss of synchronism of the terminal apparatus with consequent interruption to service.

For system stability it is desirable that reactance be kept low, whether it be that of transmission lines, transformers or generators. It is not feasible to reduce the reactance of the transmission lines appreciably except by building additional lines in parallel. Transformer reactance is a relatively minor part of the total and can be reduced below the normal values only at considerable cost. On this account, attention must be focused on the generators where it is economical to increase the cost to reduce the reactance below normal since such a reduction increases the capacity of the relatively much more expensive lines to carry load with less probability of service interruption due to system disturbances.

Another important consideration in maintaining synchronism is that of sustaining voltage throughout the system during a disturbance. This may be partially accomplished by the use of machines having high short-circuit ratio. Higher values than those corresponding to normal design have been decided upon for certain projects for the purpose of increasing system stability. Beyond a certain degree, it is more economical to employ quick response excitation systems which serve to accomplish the same object as increasing the short-circuit ratio, namely, that of sustaining the voltage during a disturbance.

Within the past year, the construction of machines embodying these special features for improving system stability has been undertaken for certain high head developments in California where the length of the transmission lines and the amounts of power involved are such as to cause the stability to be an important problem. Machines of special characteristics are also under construction for certain low head hydroelectric devel-

opments in the East and the South where the reactance of the slow-speed machines is of necessity relatively high and where the amounts of power to be transmitted are very large.

*Relation between Dielectric Tests on New and Used Machines.* This subject has been referred to the Standards Subcommittee and it is intended that a paper should be prepared for the purpose of setting forth the principal considerations and a suggested standard.

*Characteristics of Synchronous Machines.* Supplementing a study of the characteristics of synchronous machines by an extension of Blondel's theory of two reactions as mentioned in the report of last year, the second part of the series of papers by Doherty and Nickle should also have been mentioned, which treated the steady-state, power-angle characteristics. A further study has now been presented by these authors on the torque-angle characteristics under transient conditions and a further study of torque characteristics under short-circuit and transient conditions has been promised. Another contribution to this subject has been made by Mr. H. V. Putman in a paper presented to the Institute. Results of experimental studies of the transverse armature reaction in synchronous machines have been presented in a paper to the Institute by Prof. J. F. H. Douglas to show that the effect of transverse reaction can be most accurately estimated by the use of a m. m. f. diagram.

*Stray Load Losses.* Sources of stray losses and means of their reduction and elimination present a field of study which is of considerable importance in the never-ending endeavor to improve the efficiency of electrical machines. Papers have been presented to the Institute dealing with several phases of this subject. An analysis of the m. m. f. waves of polyphase windings of the fractional slot or irregular types shows the possibility of the existence of sub-synchronous harmonics having wavelengths greater than two-pole pitches which may induce currents in the damper windings of synchronous machines. Connection arrangements of this type of windings have been investigated for the purpose of preventing these losses. The existence of eddy current losses in the copper of armature windings has been a fertile field of investigation both as to a means of determining their magnitude and their reduction. Recent studies have resulted in simple conductor transpositions and arrangements that have been effective in almost entirely eliminating these losses. Investigations made by the calorimetric method in connection with several turbo generators gave results that appear to confirm the correctness of assuming the stray load losses being equal to the additional losses under sustained short-circuit conditions.

One of the colleges has undertaken a series of experiments on methods of determining load losses of synchronous machines which, it is said, gives promise of adding materially to the knowledge of this subject. It is hoped that the results of these experiments will be presented to the Institute during the coming year.

*Synchronous Converters.* A treatment of the theory of the converter has been presented that is based on the method of "harmonic analysis" by which any regularly repeating function may be represented, and presenting a conception of the internal voltages, currents, heating and armature reactions as related to the physical structure of the simple converter and as related to the passage of time which may be called space and time relations.

*Synchronous Motors.* A theory for the calculation of the complete starting performance of synchronous motors has been presented which utilizes a system of negatively rotating vectors to take care of the unbalance in the damper winding which is not continuous.

*Reactances for Direct Current.* A direct method of design for the predetermination of the correct air-gap in reactances and transformers which are to be used with direct current has been offered. This subject is of particular importance in building rectifier filters for radio telephone work.

*Magnetic Fields.* The distribution of magnetic flux is a very important factor in the design of electrical apparatus and there is need of methods for determining the magnetic fields with a reasonable degree of accuracy. A rather complete treatment of this subject has been presented to the Institute in a group of papers covering the graphical method from the standpoint of the theoretical considerations, comparison between calculations and tests and the practical application to a particular type of machine.

*Dielectric Tests on Windings of Large Alternators.* The attention of the Subcommittee on Research has been called to the question of whether or not there should be a difference in the value of voltage applied in making dielectric tests on one phase to other phases connected to ground and from all phases connected together to ground. Information on this subject is desired.

*Effect of Damper Windings in Alternators upon Single-Phase Short Circuits.* It is customary in Europe to add dampers to the field structures of alternators to enable them to more effectively carry unbalanced loads and reduce peak voltages when single-phase short circuits occur. This subject is included in a research report by the Department of Electrical Engineering of the M. I. T. of June 1926, and information is desired as to whether it is advisable to follow this practise in America.

*Evaluation of Conventional Losses.* A discussion of the paragraph under this heading in this committee's report of last year has suggested that suitable commercial test methods of determining the internal voltage drop of an alternator winding which is due to leakage reactance should be devised so that the real core loss under load conditions could be taken into account in figuring the efficiency instead of using the no-load value of core loss which may be considerably lower. If such tests could be made, the value of the conventional efficiency would

more nearly approach the real efficiency. The value of this drop in field ampere-turns might be taken from the test short-circuit impedance curve if the armature reaction in ampere-turns were known. This latter term can be quite accurately calculated from the armature winding data but the test codes of the A. I. E. E. Standards are based upon the principle that the characteristics must be determined from only those quantities which can be directly measured by test. Some reasonably accurate method of measuring the leakage reactance would be a valuable addition to the present standards.

*Alternator Short Circuits.* The work done previously on this subject has been to determine the amount of current that will flow for various conditions of short circuit. The torque produced during a short circuit is also of importance and an instrument has been developed which will give a record of the instantaneous values of torque during a short circuit or similar transient condition. It is also possible with this instrument to investigate the synchronizing power of a machine and tests are being made at the present time to study this synchronizing power as well as the short-circuit torque of a number of machines.

Within the past few years, the methods of calculating phase-to-ground and phase-to-phase short-circuit values as well as the currents flowing for any abnormally unbalanced operating condition have been greatly simplified by the use of the system of symmetrical coordinates developed by Mr. C. L. Fortescue. In order to apply this method of symmetrical coordinates, it is necessary to have a knowledge of the impedance of the rotating machines to zero and negative phase sequence voltages. A great deal of experimental work has been done to determine the proper method of determining these impedances. A series of rather simple shop tests has been devised to obtain the desired information and during the past year a number of machines has been tested to find the values of their impedance to zero and negative phase sequence voltages.

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## Standards

The following report has been made by Mr. E. C. Stone, Chairman of the Subcommittee on Standards.

*General.* Following the policy laid down by the Chairman of the Committee on Electrical Machinery, the Committee on Standards has kept in close touch with developments in the manufacturing and operating fields, and has attempted to sense the needs, as they have arisen, for modification or further development of the present standards and for the setting up of new standards.

By consistently following the policy of having subcommittees continuously at work on the revision and further development of standards for electrical machinery, it is hoped that the Institute standards in this field may be kept fully abreast of the times and adequate to meet the changing conditions under which electrical machinery is called upon to operate.

The various subcommittees have been actively at work during the past year, have initiated a number of proposals for modification of old and creation of new standards and have carefully worked up a number of definite recommendations which has been formally proposed to the Standards Committee of the Institute.

The preparation of standards covering two types of apparatus, mercury arc rectifiers and constant current transformers, not covered by present standards, has been started and definite recommendations may be expected within another year.

A number of changes in, and additions to, present standards on synchronous machines and on transformers, A. I. E. E. Standards Nos. 7 and 13, has been recommended. Additions of importance include the following:

Method for the calculation of natural frequency for synchronous motors driving reciprocating machinery.

Definitions for short-circuit ratio, per cent synchronous impedance and per cent transient reactance.

Definition for and method of rating grounding transformers.

Ability of transformers and reactors to withstand short-circuit current.

Method of measuring losses in transformers.

The operation of electrical machinery on a total temperature basis rather than on a temperature rise basis was actively discussed by the committee. The increasing demand under economic pressure for operation of electrical machinery in such manner as to get out of it the greatest possible capacity under all conditions, and of taking advantage of the greater capacity inherently present when a machine is operated in a temperature below that for which it was designed, was recognized, and it was agreed that the committee should give active attention to the subject. In this work the committee was instructed to cooperate with Working Committee No. 38 of the Standards Committee, Mr. Hobart, Chairman, whose function is "to revise the general principles upon which the rating of electrical machinery is based, with a view of presenting at a later date a document that will explain the connection and distinction between test specifications for rating and *operation under service conditions,* the purpose being to place before the various working committees a working basis on which service may be established for each line of apparatus."

The subject of standards for dielectric tests immediately after putting in service and periodically while in operation, was taken up actively. The investigations have shown that the problems involved are not well understood and that there is a wide variation both in opinion and practise with respect to them. Accordingly, Messrs. Gilt and Barns have promised to prepare a paper on the general subject of dielectric tests on equipment after installation, in which the principles, problems and practises will be crystalized and an attempt made to develop a definite method of arriving at a satisfactory solution to meet the various conditions that are encountered.

In the field of fractional horsepower motors, little could be done because of the unsettled status of the negotiations now under way between the N. E. M. A., A. E. I. C. and N. E. L. A. with regard to the performance characteristics of this class of motor.

There is a growing tendency among power companies to place restrictions on the permissible efficiency power factor, and starting current of fractional horsepower motors. These characteristics are particularly important in the ¼-h. p. motors used for domestic refrigerating and oil burning equipments, which at present have very poor characteristics in these respects. One company has already put out a rule requiring that all such motors connected to its lines must have an apparent efficiency not less than 42 per cent and a starting current of not more than 15 amperes at 115 volts.

The negotiations referred to above have been carefully followed by the subcommittee. It appears that definite progress has been made towards reaching an agreement at which the performance of fractional horsepower motors will be substantially improved, with a result that the over-all cost to the operator on such motors, giving consideration both to the cost of the motor and of the power to operate it, will be reduced.

The following is a brief resume of the activities of the various subcommittees.

*Standards for Alternators, Synchronous Motors, and Synchronous Machines in General.* W. J. Foster, Chairman. Revisions of the following paragraphs have been suggested:

Paragraph Number

| | |
|---|---|
| 7-66 | Definition of Open Machine. |
| 7-67 | Definition of Protected Machine. |
| 7-457 (b) | Ventilating Blower Losses. |
| 7-457 (c) | Other Auxiliary Apparatus Losses. |
| 7-465 | Determination of Losses (to include 7-472). |
| 7-467 (b) | Friction and Windage Losses of Engine Type Alternators (to include Synchronous Motors). |
| 7-470 | Stray Load Losses. |
| 7-551 | Insulation Resistance—Minimum Values. |

Additions to this pamphlet have been recommended to cover the following:

Method of Calculation of Natural Frequency of Synchronous Motors Driving Reciprocating Machinery.

Definition, Short-Circuit Ratio.

Definition, Per Cent Synchronous Impedance.

Definition, Per Cent Transient Reactance.

*Standards for Transformers, Induction Regulators and Reactors.* G. Faccioli, Chairman. The following new paragraphs have been recommended:

13-161 Grounding Transformers—Definition and Rating.

13-254 Grounding Transformers—Momentary Load Limitations.

Revisions of the following paragraphs have been recommended:

13-250 Short-Circuit Current of Transformers—Momentary Load Limitations.

13-252 Current Limiting Reactors—Momentary Load Limitations.

13-306 Measurement of Losses in Transformers.

The following subjects are suggested for attention during the next year:

Guaranteed Secondary Voltage of Step-Up Transformers under No-Load Conditions.

Cooling of Air-Blast Transformer Windings after Shut-Down.

Self-Protection of Transformers against Impulse Transient Voltages.

Operation of Transformers by Temperature.

*Standards for Synchronous Converters.* C. H. Sanderson, Chairman. The further study of the following subjects for the revision of Standards No. 8 is recommended:

Normal Rating.

Measurement of Cooling Air.

Quantity of Air Required for Cooling.

Short-Circuit Protection.

*Standards for Mercury Arc Rectifiers.* B. G. Jamieson, Chairman. This subcommittee was created through the request of the Standards Committee of the Institute at the January 1927 meeting. It is intended that it will develop as rapidly as possible definite standards for mercury arc rectifiers.

*Standards for Constant Current Regulating Transformers.* H. C. Louis, Chairman. This subcommittee was organized at the time of the Winter Convention and it is expected to develop definite standards for constant current regulating transformers.

*Standards for Fractional Horsepower Motors.* E. C. Stone, Chairman. On account of the unsettled status of fractional horsepower motors due to the negotiations now under way between the N. E. M. A., A. E. I. C. and the N. E. L. A., it has been impossible to formulate any definite recommendations on this subject.

It is recommended that this subcommittee be continued next year and that the A. I. E. E. Standard No. 10 covering this subject be reviewed and such revisions recommended as may be necessary to fit in with the revised practise set up.

## Ventilation

The ventilation of machinery is a very important consideration not only in regard to the cooling of the machine itself and the supply of an adequate amount of clean, cool air but also as a means of deadening noises inherent in the operation of large and high speed machines. In the endeavor to realize every possible economy for obtaining high efficiencies, attention is being paid to relatively small features of construction to obtain small resistances to the passage of cooling air, and much attention has been paid to forms of fans. The importance of paying attention to small details in improving efficiencies of turbo alternators has led to investigations in the laboratory by the use of a model in which changes in fingers, slot wedges and dimensions of slots can be readily made and the effects determined. Tests are also being made to study the flow of air through rotors.

The report of this committee for last year mentioned that closed ventilation systems had been adopted for hydroelectric plants. The question may well be asked as to what consideration would make it advisable or desirable to use a closed system in a water power plant. The many illustrations of water power plants which are published in the current literature show locations remote from sources of smoke and dust which are not associated in our minds with broad expanses of water and wilderness. There are often conditions surrounding the location of power houses that make it advisable to provide a closed system. Hydroelectric plants located on rivers in the midst of manufacturing plants where much coal is burned have as much need of this type of ventilation as the turbo generators in steam plants in the same locality. There are also conditions in some remote locations which make closed systems advisable, such as severe dust storms in barren districts. It often happens that the initial installation in a hydroelectric development is only a small part of the final capacity and there may be construction work going on over a long period after the first few units have been put into operation with considerable dust from masonry work in the air. In an instance of this kind, it was found that the generators had become sufficiently clogged with dust to raise

their temperature 10 deg. One installation of eight 12,550-kv-a., 100-rev. per min. waterwheel-driven generators includes closed ventilation systems. Probably the largest waterwheel-driven generator to be provided with this system is a 30,000-kv-a., 300-rev. per min. vertical unit. In these installations, the air coolers are located in enclosures immediately behind the stator frames, and after passing through them, enter ducts leading to the pit underneath the generators. In the case of the 30,000-kv-a. generator, the air is returned to the space above the rotor also. The coolers are arranged so that they can be lifted vertically out of their pockets for repair or replacement without disturbing any part of the generator themselves.

Another unusual application of the closed system of ventilation is in connection with a German Diesel-engine-driven 13,000-kv-a., 94 rev. per min. alternator.

Much valuable data for future design work regarding hydrogen cooling have been obtained from thorough tests on a 6250-kv-a., 3600-rev. per min., 13,200-volt turbo generator. These tests were highly gratifying and indicated that practically the same benefits may be obtained as may be expected from theoretical considerations. There are indications that hydrogen cooling may eventually be used for large synchronous condensers and frequency converters. It has been suggested that helium could be used with advantage in the place of hydrogen and this possibility is being investigated. A seal has been developed to prevent the loss of hydrogen or the admission of air at the section where the shaft of the machine enters the end bell. Tests made over long periods of time on this type of seal have proven very satisfactory. Tests have also been made on heat-flow across laminations when surrounded by hydrogen.

The necessity of minimizing the noises given out by rotating machinery in substations located in business and residential areas has presented some difficult problems, especially in connection with d-c. machinery. It is a comparatively simple matter to enclose a synchronous motor so that the noises are quite effectively deadened but in the case of a d-c. generator or a rotary converter, the necessity of providing ready access to the commutator brushes presents serious difficulties and the accumulation of metallic and carbon dust becomes a serious contributing factor toward insulation failures.

An early attempt to enclose a rotary converter consisted of a housing in the form of a wired glass and steel framework closely shrouding the commutator and mounted directly on the arms of the brush spider. A metal housing covered the collector rings and pedestal with sufficient room to allow an operator to enter the housing and inspect the rings and brushes. Test showed, however, that this arrangement hindered the free ventilation of the commutator and from an operating point of view the commutator was too inaccessible. A later attempt which has proved successful has taken the form of a large semi-cylindrical steel housing of about the same size as the over-all projected dimensions of the converter and of slightly greater height. Doors are provided at each end while steps on the bearing pedestals with suitable screens, guard rails and adequate lighting make the rings and commutator safely and easily accessible. Air is introduced through the pit at the d-c. end, a small part being admitted under the collector rings and passing axially through the machine; it is discharged into the exhaust ducts from the top of the collector end of the enclosure. This scheme has been successfully applied to 4200-kw., 12-phase converters having their two transformers mounted on the base plate. Blowers located in the basement beneath the converters are used to force the air through the housings. Some 2100-kw., six-phase converters have been similarly equipped.

During the past year extensive experimental tests have been made to determine the surface heat transfers in electrical machinery with air flowing at various velocities through radial and axial ducts. Investigations have been made to determine the influence of shape, size, cross-section, condition of the surface, mean temperature and several other factors.

The most important fact brought out in these tests is that the rate of heat transfer is not constant along the path of air-flow but varies in value from point to point along the path. This variation in the rate of heat liberation for a constant air velocity in a given duct is caused by the changes in the turbulency of the air-flow along the duct. As a result of this change of turbulency, it is found that the rate of heat transfer near the entrance of a duct is about twice that at a point further along where stable flow conditions are found. This explains why electrical machines with short duct length have a capacity in proportion to their surface greater than those with similar ducts but with longer air flow paths. This also explains why the surface heat transfer coefficient of a duct, averaged over its total length, will be an inverse function of the length. It also explains why results as given by experiments on ducts of various length should vary.

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### Water-Wheel Generators

Probably the most notable water-wheel-driven generators of the past year are the seven machines now under construction for the Conowingo Development. These alternators are notable not only because of their size but also because of the fact that they are to supply power for the first 220-kv. transmission line in the eastern part of the United States. They are rated 40,000-kv-a., 90 per cent power factor, 81.8 rev. per min., 60 cycles, 13,800 volts, and are the largest in physical dimensions of any electrical machines that have ever been built. They are being built by two manufacturers, and by a large degree of cooperation between them, it has been possible to obtain similarity in characteristics and appearance and interchangeability of some important mechanical parts. The outside diameter of the stator frame is 38 ft. One manufacturer has made use of steel plate construction almost exclusively for the mechanical parts of the stator frame and the rotor. The rotor rim will consist of heavy rolled plates in several layers overlapped so as to give the greater strength for the amount of material used and fastened together with bolts and dowels. The pole pieces will be fastened with bolts through the rim. The stator frame is of the welded steel plate construction and greater uniformity in shape has been obtained than is possible with castings. The largest capacity thrust bearings ever built will be required for these generators. Their capacity will be a total load of 750 tons.

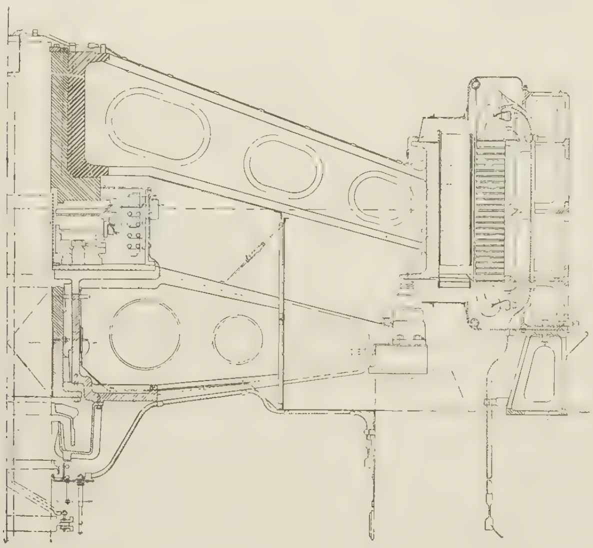

Fig. 1—Section of 27,500-Kv-a., 90-Rev. per min. Vertical-Shaft Alternator with Overhung Rotor

On account of the stability characteristics desirable for operation with the 220-kv. transmission line, the generators described above have a short-circuit ratio of 1.25 which is somewhat higher than has been found satisfactory for nearly all other hydroelectric developments. As a further aid in securing continuous parallel operation without hunting or dropping out of step during disturbances on the system, a scheme of high-speed excitation is being used. As in the case of the large generators at Niagara Falls, each main generator has direct-connected to its shaft a service generator which supplies power to a high-speed motor-generator set for providing excitation for the main generator. The service generator is provided with its own direct-connected exciter. The generator of the main exciter set will be separately excited by a suitable direct-connected exciter. To take full advantage of the high-speed excitation provided by this scheme, special voltage regulators are being used to control the main generator excitation through the control of the field current of the exciter generator. The fields of the exciter generator will be connected in two parallel circuits in order to obtain an effect equivalent to that of using double potential on the whole field connected in series. Generators having the same scheme of excitation have been installed in power houses on the Gatineau River in Quebec for supplying power to the 260-mile transmission from Ottawa to Toronto. One of these generators is rated 32,000 kv-a., 90 per cent power factor, 100 rev. per min., 6600 volts, 25 cycles, and the other is rated 22,500 kv-a., 88.3 rev. per min.

The largest vertical shaft water-wheel-driven alternators yet built in Europe are now under construction. They are rated 35,000 kv-a. at 337 rev. per min. and 375 rev. per min., 10,000 volts, 40 cycles. These machines are equipped with direct-connected main and auxiliary exciters. The rotors are made up of two wheels, each consisting of five cast steel disks bolted together. The pole pieces are dovetailed to the rotor spider.

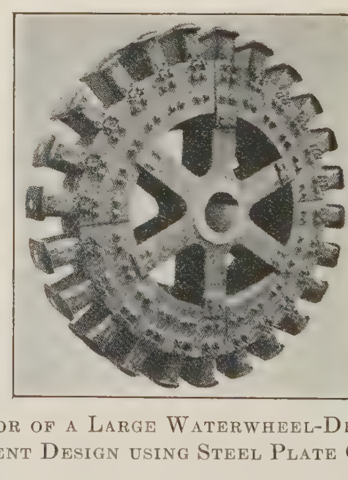

Fig. 2—Rotor of a Large Waterwheel-Driven Alternator of Recent Design using Steel Plate Construction

There are under construction three of the largest vertical shaft water-wheel generators of the "umbrella" type yet built. Two of them are rated 27,500 kv-a., 80 per cent power factor, 90 rev. per min., 13,800 volts and the other is rated 22,500 kv-a., 75 rev. per min., 60 cycles. With this construction, a common shaft is used for generator and water-wheel and the thrust and guide

bearings are located beneath the rotor. There is no guide bearing above the rotor. The ventilation arrangement is noteworthy in that no air is taken from the wheel pit and no air currents pass over the bearing oil pans to draw oil vapour into the generator. A number of smaller generators of this type has now been put into operation and their operation has proved satisfactory.

European manufacturers of water-wheel equipment are apparently finding it more economical to offer geared units for low head installations. An installation on the Trent River in Ontario consists of a 1400-h. p., 120-rev. per min. vertical shaft turbine geared to a 600-rev. per min. horizontal shaft alternator through a set of helical bevel gears which are claimed to have an efficiency of 98 per cent. Some recent German plants contain vertical shaft turbines driving vertical shaft alternators through double spiral gears.

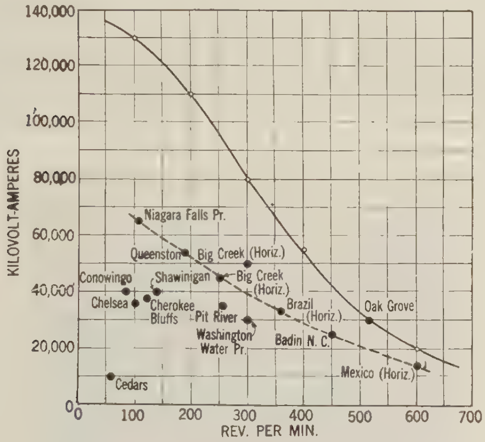


Fig. 3—Comparison of Ratings of Existing Salient Pole Alternators with Ratings which Manufacturers are Prepared to Build

The full line curve shows ratings which manufacturers are prepared to build as mentioned in the June 1926 report of this committee

During the year a very large automatic hydroelectric station has been put into operation. It consists of a 17,500-h. p. vertical turbine driving a 13,333 kv-a., 6600-volt, 225-rev. per min. generator and is controlled from a station seven miles distant. Another large generator rated 9000 kv-a. arranged for full automatic control has been put into operation.

In the report of this committee last year, there was given a list of large ratings at different speeds which manufacturers were prepared to build. No doubt, if the necessity should arise, greater ratings could be constructed. A reader who was interested in knowing how close the ratings of machines already built came to these limits has plotted the list of maximum ratings and speeds in the form of a curve and added the more outstanding ratings that have been built. The curve and plot is reproduced to show what appears to be the limit line of hydroelectric unit capacities that have been considered economical up to the present time. It will be noticed that the highest ratings at different speeds of machines built or under construction fall on a well defined curve with the exception of two machines that are above the curve.

Recent developments in the design of Pelton wheel water turbines promise that larger horizontal shaft generators than heretofore built are possible requirements of the future. The standard arrangement of units with this type of turbine is to mount a runner on each end of the generator shaft. Units of this type have been built for capacities of 40,000 h. p. and 56,000 h. p. and studies have been made of still greater capacity wheels which may be built when the proper economic conditions are presented. There are now being built two of the largest capacity alternators for this arrangement that have been produced. One of these is rated 50,000 kv-a., 60 cycles, at 300 rev. per min. and the other is rated 45,000 kv-a., 50 cycles at 250 rev. per min.

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## Turbo Alternators

The trend of development during the past year has been toward larger units. In connection with the manufacture, shipment, and installation of the large alternators now being produced, there has been an extension of the use of the skeleton frame construction for stators, and also in speeds of 1500 and 1800 rev. per min.

The old type of construction made a final unit which was necessarily heavy and usually too large for shipment on the railways. With the skeleton frame construction, the frame is strong enough to support itself during machining and assembly. Special bolted-on plates and trunnions for each frame facilitate handling during assembly at the works, loading and unloading during shipment, and final erection at the destination. The over-all dimensions of the frame, assembled for shipment, allow the completely assembled unit to be shipped direct to its destination. The ventilation requirements are cared for by an external superstructure of sheet metal applied at the destination. With this construction, 1800-rev. per min. turbine generators up to 75,000 kv-a. can be built and wound at the works and shipped complete. As a result of this, large turbine generators can be tested at the works, the freight charges are reduced, handling during assembly, shipment and erection is made easier, closer inspection is made possi-

ble during manufacture, and there is less confusion to the purchaser when shipment is made.

There has been considerable activity in developing new types of stator windings, involving transposition of strands in each conductor, and transpositions at the heads of the machine, or in the connections. The use of half-coils is becoming more common practise among the different manufacturers. It has been found that the use of continuous coils and the control of the eddy current loss factor by transposing the strands of each conductor at one end of the machine is satisfactory up to about 50,000 kv-a. In larger capacity machines, coil length and weight are so great that it is difficult to handle the coils during manufacture and assembly. This has favored the use of half-coils, especially in view of the facility with which damaged coils can be replaced in the machine.

To make the eddy current loss in half-coils as low as in continuous coils, either elaborate transposition of the strands at each end of the machine or transposition of the strands inside the armature core is necessary. Complete external transposition of half-coils is undesirable because of the large number of complicated connectors and the large space required for connection. For these reasons, types of half-coil construction are being used in which the strands of each conductor are transposed in the slot portion. One construction provides a complete transposition in the slot of all the strands in the conductor as one group while in another construction the strands are arranged in small groups and the strands of each group are transposed internally while the groups are transposed at the ends. These constructions permit the use of coils which are relatively easy to handle and assemble and yet make the eddy current losses as low as possible.

The past year has seen the realization of the predicted possibilities in large high-speed turbo generators which were mentioned in the report of this committee last year. There are under construction generators of the following ratings:

*Single-Shaft Units.*

100,000 kv-a., 90 per cent power factor, 1500 rev. per min.

75,000 kv-a., 80 per cent power factor, 1800 rev. per min.

*Triple-Shaft Units.*

Two—64,706 kv-a., 85 per cent power factor, 1800 rev. per min. and one 57,647 kv-a., 85 per cent power factor, 1800 rev. per min. with two 4286-kv-a. house service generators to form a 165,000-kw. unit.

Two—72,941 kv-a., 85 per cent power factor, 1800 rev. per min. and one 89,412 kv-a. 85 per cent power factor, 1800 rev. per min. with two 5333-kv-a. house service generators to form a 208,000 kw. unit.

The present tendency to very large generating units and ever increasing station capacities has made the switching problem, on account of the enormous currents involved, a serious one. This situation is being met in some instances by connecting step-up transformers directly to the generator terminals and doing all the switching on the high-tension side of the transformers. In other cases, the generators are being built to operate at voltages considerably higher than those previously employed. As examples of the latter practise, the two 100,000-kv-a. units mentioned above are being constructed for 16,500-volt operation; the main generators of the 208,000-kw. triple shaft unit above referred to will operate at 22,000 volts, and there is also under construction a single-shaft generator of 61,675-kv-a. capacity which will operate at 22,000 volts. All of these will have dielectric tests in accordance with the A. I. E. E. Standard, i. e., twice normal voltage plus 1000 volts.

During the year some large two-shaft units have been put into operation. One of these consists of two 40,000-kw. generators. The turbine and generators are operated as a unit, the two generators being solidly tied to each other and to an auto-transformer stepping up to 27,600 volts with switching on the high-tension side only. The neutral points of both generators and auto-

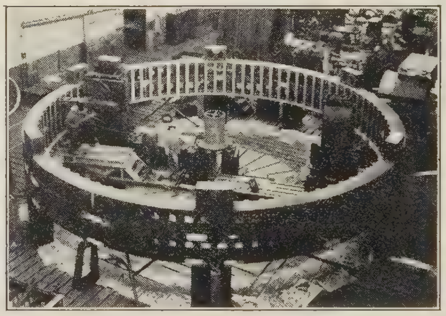

FIG. 4—SHOP VIEW OF STATOR FRAME FOR 40,000-KV-A. VERTICAL SHAFT ALTERNATOR

For Conowingo Development

transformers are solidly grounded. The unit is started with field on both generators, the low-pressure element starting as a motor. The two generators are identical and are each rated at 40,000 kw., 1800 rev. per min., 13,800 volts, 90 per cent power factor. The generators also have a one-hour overload rating of 80,000 kw. at 80 per cent power factor. A 250-volt exciter is direct-connected to the generator of the high-pressure element. Each generator has its own field rheostat but the two face plates are coupled together and operated as a unit by a single pilot motor. A closed cooling system is used for each generator.

Another unit comprises a 64,700-kv-a., 85 per cent power factor, 1200-rev. per min. generator, a 38,825-kv-a., 85 per cent power factor, 1800-rev. per min. generator and a 4666-kv-a., 75 per cent power factor, 1800-rev. per min. house service generator making a combined capacity of 91,500 kw.

Still another two-shaft unit which is under construction consists of an 88,200-kv-a., 85 per cent power factor, 1800-rev. per min. generator and a 100,000-kv-a.,

95 per cent power factor, 1200-rev. per min. generator. Both generators are wound for 13,800 volts.

Two 62,500-kv-a., 1800-rev. per min. generators which have been put into service show by performance that the rating can be increased to 70,600 kv-a. without exceeding the original temperature guarantees and without change. They have a test efficiency of 98 per cent. Another manufacturer has completed a 59,000-kv-a., 12,000-volt, 1800-rev. per min. turbo generator which

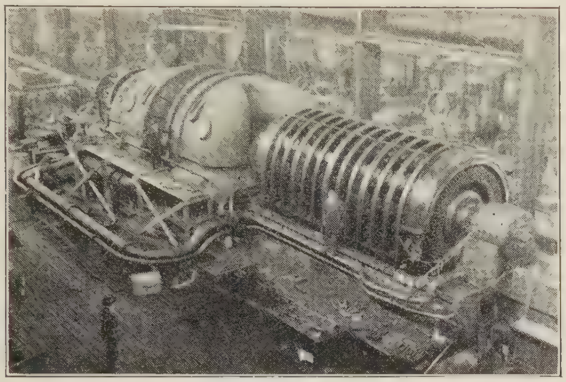

Fig. 5—Shop View of 59,000-Kv-a., 1800-Rev. per min. Steam Turbine-Alternator Unit showing Skeleton Frame Construction

will soon go into operation. This single-shaft set is to be ventilated by two external blowers and the armature winding has transposed conductors.

During the year, several of the European manufacturers have built 50-cycle turbo generators at 3000 rev. per min., in sizes from 30,000 kv-a. to 37,500 kv-a., but the experience of some of these companies in testing the generators before shipment has not been reassuring. In consequence, at least one of the principal manufacturers

Fig. 6—80,000-Kw. Cross-Compound Turbo Alternator Set

has decided to build 30,000 kv-a. hereafter, at 1500 rev. per min., instead of 3000.

In England there has been built a 31,250-kv-a., 80 per cent power factor generator which is remarkable for its voltage. It is wound for a terminal voltage of 33,000 volts and in order to avoid increasing the dimensions of the machine unduly, due to the thickness of the insulation, a special arrangement has been used to keep the voltage at a low value between adjacent conductors and ground. This high voltage would appear to be an innovation but it should be recalled that a 500-kv-a., 30,000-volt water-wheel-driven generator was built for the city of Rome about 20 years ago, is reported to have operated all that time without breakdown.

Tests made to determine the additional losses in turbo alternators due to stray field have shown that the short-circuit losses can be reduced if non-magnetic rotor retaining end rings are used. Laminated stator end flanges and laminated magnetic shields attached to the stator flanges have been proved advantageous and a number of machines has been built with these features.

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## Transformers

The design of a transformer is often influenced by space limitations. To meet special limitations, individual radiators may be removed from the sides of the transformer tank and mounted in a single group. This arrangement has been used on an 89,000-kv-a. bank of self-cooled auto-transformers. The single-phase units which comprise this tank are the largest transformers on which radiators have been mounted apart from the transformer.

The development of the load ratio transformers which was reported last year has justified the claims for its growing importance. There has been a continual growth in the use of transformers arranged for load ratio for tying-in two operating systems for properly distributing the load over different portions of the same system, and for electrolytic and metallurgic processes in industrial service.

The voltage range for which these equipments were designed varied within wide limits, the maximum to

date being 120 per cent range in voltage in 18 ratios, and the minimum 10 per cent voltage variation in nine ratios. The largest banks so operated are as follows:

Three-phase, water-cooled, 60-cycle regulating autotransformer capable of handling 60,000 kv-a. for use with three single-phase, 20,000-kv-a. units rated 132,000 grounded Y, 36,000 grounded Y, 12,000 volts.

Automatic control by means of a contact making voltmeter was provided for two three-phase, self-cooled, radiator type transformers of 10,000-kv-a., 60-cycle output.

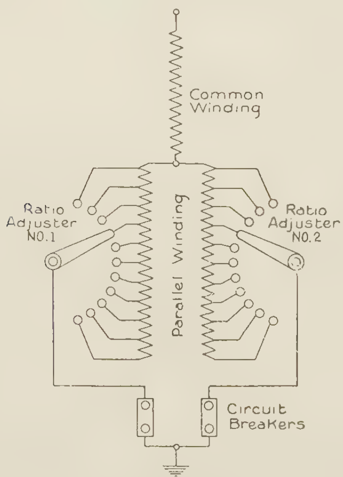


Fig. 7—Diagram of Typical Circuit Arrangement for Automatic Load Ratio Control of a Power Transformer with the Two-Winding Arrangement

These machines transformed 11,000 volts to feed a grounded Y, 41,400-volt system. To adjust the line voltage in accordance with the changing load, the high-voltage windings have 11 taps of 2½ per cent each. To permit a change of taps without interrupting the load, a part of the 41,400-volt winding is made in two sections, operating normally in parallel and dividing the load equally. Each of these winding halves is connected to an 11-point ratio adjuster and the resulting circuits brought out of the transformer tank and led to two three-phase circuit breakers.

It is thus possible during the tap-changing period to open-circuit one section in each phase, and change the voltage tap in this open-circuited section while the other section temporarily carries the entire load of the transformer. Copper of ample cross-section and the very short transition period make this possible. The same change is then made in the second half. The entire change from one voltage tap to the next requires only eight sec. For a brief period, less than 1½ sec., when both breakers are closed but the two ratio adjusters are one tap apart, an internal circulating current exists, which, however, is kept within predetermined limits by sufficient inherent reactance in the transformer windings.

A motor-operated mechanism mounted on the transformer truck insures a properly timed operation of the internal ratio adjusters and the external circuit breakers. For the proper execution of the tap-changing cycle, it is essential that the three corresponding ratio adjusters of the three phases move simultaneously from one tap to the next; therefore these ratio adjusters are mounted together on the same shaft with full phase insulation between them. The resulting two stacks of adjusters are arranged in a vertical position along the coil stacks of the transformer, and their two main shafts connect on top to a special internal intermittent gear. Turning the driving shaft of this gear train one complete revolution will first change one set of the three adjusters one step, then lock this set, and then turn the second set one step.

Contact making voltmeters relieve the operator of any manual starting of the mechanism. If the line voltage deviates from a set value for a period longer than a predetermined time value, the tap-changing mechanism is automatically put in motion in one direction or the other to bring the voltage back to normal. A positive but adjustable time delay is insured by a relay, driven by a small induction motor. Between the motor shaft and the contact making element, a train of gears with a gear shift mechanism is introduced, allowing adjustment from one sec. to 30 min.

Two contact making voltmeters are used on each of the two transformers, one adjusted to respond to a narrow range of voltage variations, while the other one is set for much wider differences in voltage. If the line voltage rises or drops only slightly, and if this condition persists long enough to bridge the introduced time delay, the transformer will shift to the next proper tap. If, on the other hand, a considerable rise or drop occurs, the second contact making voltmeter will respond and will cause immediate adjustment without any time delay. The necessary instruments, relays, timing devices, etc., are arranged on two switch panels.

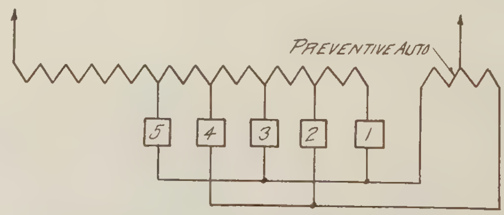


Fig. 8—Diagram of Typical Circuit Arrangement for Load Ratio Control of a Power Transformer with the Self Protecting Auto-Transformer and Single-Winding Arrangement

A large number of transformers has been built during the past year with external auxiliary equipment for changing taps under load. A simplification of the problem of taps changing under load is claimed for a new development of the single-winding scheme. By use of a self-protecting preventive auto-transformer, only one switch operation is required to change the voltage ratio of the transformer under load and protective equipment is not required for the transformer windings as no winding is overloaded during the change in taps. This method of tap changing under load permits mounting all the

switches external to the transformer tanks and requires a minimum number of switches.

The following is a description of the operation of the single-winding arrangement shown on the schematic diagram Fig. 8. On position No. 1 with switch No. 1 closed, one-half of the preventive auto-transformer carries the load current of the main transformer. The change from voltage position No. 1 to voltage position No. 2 is made by the single operation of closing switch No. 2. In this second position, each half of the preventive auto-transformer winding carries half of the load current of the main transformer and the voltage obtained is equivalent to a voltage midway between taps. The resultant current in the two halves of the auto-transformer will be the vector sum of the exciting current of the auto-transformer and one-half of the load current. The switching cycle as given above is repeated throughout the entire range of taps. As a switch is opened only upon each alternate voltage position, two voltage positions are obtained for each switching cycle, which is relatively light duty cycle for tap changing service. A slight inequality in voltage steps is found in changing from one voltage position to the next, due to the change in reactance on alternate positions. The reactance difference during this cycle is an invert function of the circulating current which is present when the auto-transformer is connected across adjacent taps and is controlled by the use of suitable air-gaps in the core of the auto-transformer. By this means, the reactance variation may be reduced to a minimum so the voltage difference is small and not objectionable.

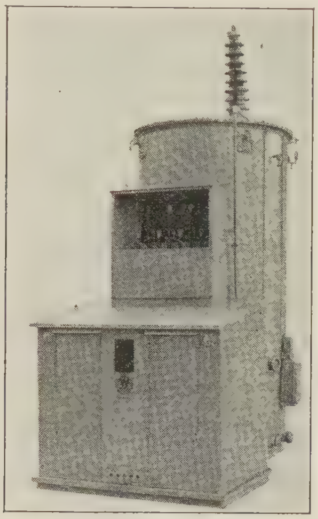

Fig. 9—20,000 Kv-a., 60-Cycle, Single-Phase, 13,200/12,000-Volt Power Transformer with Load Ratio Changer Placed in Grounded End of High Voltage Side

Two 36,000-kv-a. transformer banks have been installed using the transformer under load. The nominal voltage of the transformer banks is 132,000 to 11,500 volts with plus or minus 10 per cent voltage variation under load on the low-voltage side. The tap changing equipment used in this installation is the first equipment built with complete automatic control. As the low voltage raises and lowers with load variation, the tap changing mechanism automatically changes taps to compensate for the variation. If desired, the tap changer may also be operated by a remote control switch, or, in case of emergency, manual operation may be used.

During the last year, the largest artificially-cooled unit built was a 66,667-kv-a., 25-cycle auto-transformer. It is the largest transformer so far constructed in the United States, not only in rating, but in physical dimensions. For instance, it required 36 tons of steel and 17 tons of copper for the windings. The total weight including oil exceeded 120 tons. This transformer is utilized to step up the voltage of a turbine-generator line from 12,000 to 24,500 volts and its equivalent rating as a transformer is 34,000 kv-a.

Four single-phase auto-transformers of record size were also built for air cooling. They are rated 30,000 kv-a., 220,000 Y, 125,000 Y, 10,640 volts. These transformers have a larger capacity and exceed in physical dimensions any transformer of this type so far constructed. The conservator which contains 1300 gallons of oil is in itself equivalent in dimensions to the tank required for a 2500-kv-a., 60,000-volt transformer. The weight of the conservator is approximately five tons and the total weight of the transformer exceeds 130 tons.

In connection with the transmission of power from the Conowingo development, there will be required 580,000 kv-a. in 220-kv. transformers. The step-up service at the generating station will require 13 water-cooled transformers rated 26,667 kv-a., 220 kv. These will be connected in banks of 80,000 kv-a. In the step-down substation, there will be seven 33,333-kv. a., 220-kv. straight self-cooled, three-winding transformers to step the voltage down to 66 kv. These will be connected in banks of 100,000 kv-a. and will be arranged for ratio changing under load. These will be more than 50 per cent greater in rating than the largest self-cooled, single-phase transformers reported last year.

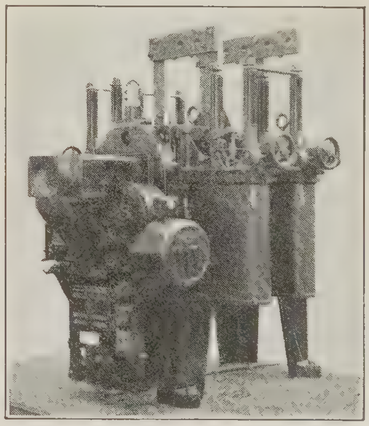

Fig. 10—Circuit Breakers and Operating Mechanism for Load Ratio Changer of 20,000-Kv-a. Transformer and Arranged for Motor or Hand Operation

The largest artificially cooled single-phase transformers were completed this year. They are rated at 31,400 kv-a., 60 cycles, 12,000 to 132,000 Y volts and are water-cooled. These transformers, while of greater rating, do not exceed in physical size the 28,000-kv-a., three-winding transformers shipped two years ago to Japan. These three-winding units, of American manufacture, have not been exceeded in physical size by any other water-cooled transformer. The present maximum capacity for two-winding transformers will be exceeded upon the completion of some 33,333-kv-a., two-winding transformers now under construction. The 33,333-kv-a. units are for 220,000-volt service, for which a great number of units has been constructed during the year. They are cooled by radiators with forced air cooling and are the largest size to which this method of cooling has been applied.

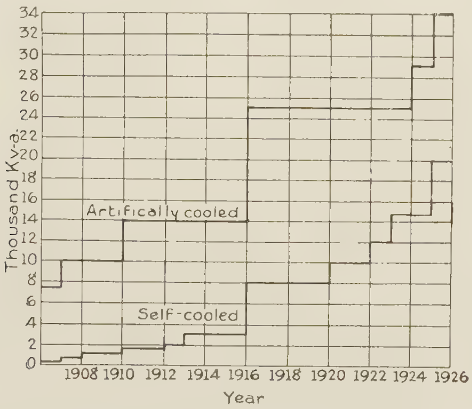


Fig. 11—Growth of Unit Capacity of Self-Cooled and Artifically-Cooled Transformers

The largest totally self-cooled transformers were recently put in operation. They are rated at 25,000 kv-a., three-phase, 60 cycles, stepping-up from 13,000 to 120,000 volts. The windings are equipped with tap changers designed for future tap changing under load. An overload capacity giving 35,000 kv-a. is obtained by means of forced oil circulation through the cooler.

The development of means to increase the rating of self-cooled transformers by the method of blowing air on the cooling surface, which originated about five years ago, has been applied to a number of large installations during the past year. It has been found that in some cases where transformer efficiency is not of prime importance, the saving effected in the transformer itself is sufficient to offset the cost of the blower and air duct equipment.

For use in underground distribution systems, a new subway transformer tank has been developed which is suitable for larger capacities, higher voltages, and heavier currents. The junction boxes form an integral part of the tank and provide adequate high- and low-voltage terminal facilities.

Peculiar conditions in connection with the marketing of both 25-cycle and 60-cycle power from the new hydroelectric developments on the Gatineau River in Quebec have called for the use of some 14,000-kv-a. water-cooled transformers suitable for use on either 25 cycles or 60 cycles without any change whatever in the windings.

The outcome of the recent attempt to formulate standard voltages will have far-reaching effects upon the transformer industry. Standard voltages and capacities will result in economies both in manufacture and use.

Recognition of the advantages of a means of changing ratios under load has resulted in a large demand for this type of transformer in Europe, as well as in America.

In the report for last year, mention was made of some large single-phase transformers for 16 2/3-cycle railway work and arranged for three voltages. The claim is made that these are the largest transformers in the world. If a 50-cycle transformer were built with the same material, its rating would be 100,000 kv-a. The design of these transformers is of particular interest because it was necessary to divide the 15,000-volt winding between the 66,000- and 132,000-volt sides to secure the necessary mechanical strength for short circuits. To meet the various magnetic conditions for the different methods of operation, it was necessary to provide a special by-pass core for the magnetic leakage fluxes.

Among the large transformers built in Europe, it is of interest to mention six 3-phase, 5-leg, 44,000-kv-a., 50-cycle units for the Rummelsburg power station.

An interesting European development along the lines of high-voltage testing transformers are some 750,000-volt units which are constructed on an entirely new principle. It has been the practise to immerse the whole active parts of such a transformer in an oil tank but in this design only the windings are oil-immersed. This is accomplished by arranging the inner and outer insulating cylinders concentrically in such a way that they form a container for the oil. This allows dispensing with expensive insulating bushings. The following advantages are claimed for this construction:

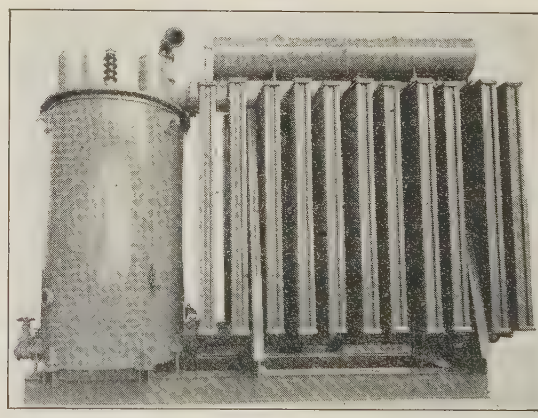

Fig. 13—29,667-Kv-a. Transformer with Radiators Mounted Apart from the Tank

1. Low manufacturing cost, owing to the absence of bushings and tanks and less oil.

2. Small floor space as compared with testing plants using multiple stage cascade connections.
3. Increased reliability, owing to independence from atmospheric influences.
4. Ability to withstand heavy loads owing to the comparatively small leakage voltage.

Tests at 1,500,000 volts have been made with two of these transformers connected in series.

What are probably the highest capacity testing transformers were constructed during the year for use in cable testing. They are rated 400 kv-a., 2300/200,000 volts, 60 cycles, single-phase.

Fig. 14—Underground Transformer

This type of transformer may be buried in the ground

The highest voltage instrument potential transformers that have been considered for commercial use have recently been designed and will be built and installed during the coming year. These will be suitable for 220 kv.

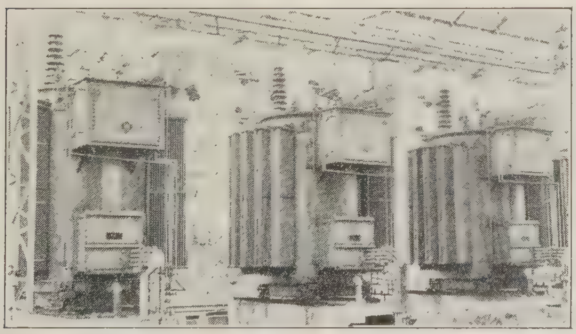

Fig. 15—36,000-Kv-a. Bank of Transformers with Complete Automatic Control of Ratio Changer under Load

Probably the largest electric furnace transformer ever built is now under construction in a Canadian factory for an aluminum plant. It is rated 15,000 kv-a., three phases, 60 cycles, 13,200-250 volts with taps on the high-tension winding to give full capacity in the low-tension winding over a range from 225 volts to 275 volts. The high current of 38,500 amperes at the 225-volt rating involves some very unusual problems in the arrangement of windings and terminals.

A year or two ago, the Power Commission of the city of Toronto was presented with the problem of dealing with objections raised by property owners in some of the better residence sections against mounting distribution transformers on poles. Arrangements were made with a manufacturer to build a few transformers that could be buried in the ground as an experiment. It was found that the ground is as effective in cooling as the air and practically the same heating was obtained from a given core and coil when buried in an underground tank as when hung on a pole in the ordinary out-door tank. The results are so satisfactory that other transformers have been ordered for regular service. These units are contained in welded tanks with an extension to the top to which is fitted a suitable man-hole cover. The whole may be buried in a lawn so that the man-hole cover is even with the surface of the ground and the primary and secondary leads carried underground to the nearest distribution pole. When it is desired to examine the transformer, the man-hole is removed to give access to the cover of the transformer tank proper. Later designs of these transformers have an arrangement whereby the taps may be changed by means of a key without removing the transformer cover. A surprising feature of the tests on the trial transformers was the fact that the snow did not melt appreciably more in the immediate vicinity of the transformer than in other parts of the lawn.

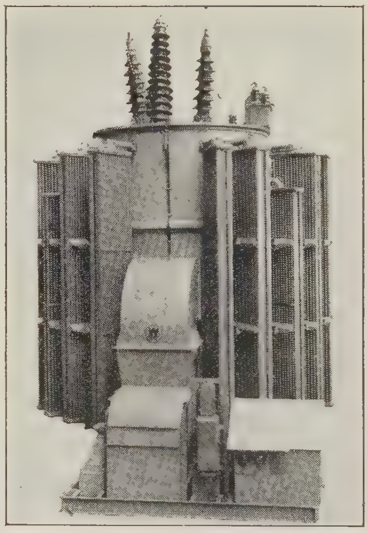

Fig. 16—33,330-Kv-a., 220,000-Volt Two-Winding Transformer Arranged with Forced Air Cooling Equipment

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## Induction Motors

The demand for squirrel-cage motors, suitable for starting at full voltage without compensator or other starting device, has very greatly increased during the past year. Where the service does not require very heavy starting torque, such as centrifugal pumps, blowers, motor-generator sets, etc., the starting current can be reduced sufficiently without reducing the starting torque beyond the requirements by simply increasing the reactance of the squirrel-cage winding. For other classes of service where a normal or even a high starting torque is required, the situation is met by adding a second higher resistance squirrel-cage to the regular working winding which still has high reactance. The high-resistance winding having a low reactance, this type of machine is commonly called a double squirrel-cage. Standard lines of motors up to 50 h. p. of these types have been brought out by several different motor manufacturers. In general the characteristics of this type of machine are such that up to and including 30 h. p., they are successfully made so that the static current is within the N. E. L. A. requirements, and the static and pull-in torque are substantially better than is possible with a single squirrel-cage winding. Generally the efficiency is practically the same as for the single squirrel-cage and the power factor is practically the same as for two-and four-pole machines but there is a reduction of a few points in the power factor of the six-pole machines and a correspondingly lower power factor as the number of poles increase.

The use of ball and roller bearings seems to be growing in favour for the number of motors with this type of bearings forms a greater part of the total sales each year. An advantage which is claimed is that motors may be shipped with the necessary lubrication ready to be put into operation and shields do not need to be changed to ceiling or wall mounting. Grease lubrication has been found satisfactory for motors up to two h. p. at 8000 rev. per min.

The principle of directing jets of air on the surface of self-cooled transformers to accelerate the convection of heat has been applied to totally enclosed induction motors by equipping them with fans arranged to blow air over the outside surface. By this arrangement it is possible to build totally enclosed motors of somewhat larger capacity and especially in the larger sizes they are less costly than the straight enclosed motors without ventilation.

The growing tendency for system interconnection is resulting in the gradual elimination of odd frequencies so that the demand for motors is very largely for the standard 60-cycle frequency. It is probable that within a short time there will be no demand for 40-cycle motors because many of the 40-cycle systems are being changed over to 60-cycle.

For many years, 220 volts has been a standard voltage for small general purpose motors and power companies have provided suitable service for this voltage. Re-

cently, due to the apparent economies of four-wire distribution for power and light services, an active demand has grown up for 200-volt motors, and it is probable that stocks of motors for this voltage will soon be regularly carried.

A very interesting development in single-phase, induction motor design was brought out by a German firm. The motor has no commutator, but is able to develop sufficient torque to make the motor suitable for railway work. This motor has two rotors on the same axis. The first rotor is synchronous and excited from a direct current source but does not transmit any torque to the shaft. The second one rotates inside the first driving the shaft and is an ordinary slip-ring motor. The synchronous rotor supplies the magnetization and it is possible to obtain unity power factor at different loads. It is also possible by increasing the excitation to compensate for the effect of voltage drop on the maximum running torque. A motor, rated 225 h. p., 50 cycles, has been built.

An induction motor with Ward-Leonard control capable of carrying peak loads of 18,000 h. p. deserves to be mentioned among large machines. This motor was recently built in Europe and was furnished for rolling mill drive.

The rapidly increasing use of fractional horsepower motors for domestic and other purposes has caused the power companies to become concerned about poor power factor conditions because there is no restriction about the performance characteristics of motors sold to the householder. The power companies have been seeking relief from this situation and recently an association of motor manufacturers, appliance manufacturers and power companies has been formed to study the situation. It has been agreed that motors for refrigerators and oil burners must have an apparent efficiency of 42 per cent and it is urged that improvements in design be made as rapidly as possible with the aim to obtain an apparent efficiency of 45½ per cent. It is possible that a single motor design will not be applicable to all domestic apparatus because of the wide range in duty.

A special application of a small motor to feeding the electrodes of an arc welding machine where it is required to operate close to the arc has led to the development of a water cooled motor. The motor has copper water tubes cast in the aluminum frame.

The desirability of domestic appliance motors being capable of operating without noise has lead to the provision of a spring support for some special application motors to eliminate the noise that is inherent in single-phase machines.

A new type of repulsion motor with a squirrel-cage in addition to the commutated winding has been developed in England for which advantages are claimed over the ordinary type.

The synchronous induction motor of the type using separate direct current excitation continues in favor in Europe. However, European literature indicates that the possibility of designing new types of self-excited machines is being actively investigated. Although the separately-excited type of motor was used commercially in America as long ago as 1911, it has not been so vigorously exploited as it has been in Europe. This year, however, a larger manufacturer has built motors of this type for driving tube mills where heavy starting torques are met and long periods of operation at full load make high power-factor motors highly desirable. This motor is the same in general construction as a wound rotor induction motor and has the same starting operation. It is provided with five collector rings for the rotor winding instead of the customary three rings. The exciter is wound for a low voltage and is connected permanently in the rotor circuit so that the starting operation is as simple as that of a wound rotor induction motor and requires no extra switching operation for the exciter. In order to limit the amount of excitation required these motors have deeper slots and considerable more copper for the rotor winding than the corresponding induction motor would have. Two motors of this type rated 900 h. p., 180 rev. per min. have been put into operation this year and a 1500 h. p. motor is being built.

FIG. 17—VERTICAL INDUCTION MOTOR FOR PUMP DRIVE

Arranged with hollow shaft through which the pump shaft extends to clutch at the top.

A brush shifting, a-c., adjustable speed commutator type of motor is now available for operation with a continuous rating at low speed as well as at high speed.

The largest adjustable speed induction motor with Scherbius control to be built in America has been installed for driving a bar mill. It is rated 6700/5000/3320 h. p. at 500/375/250 rev. per min.

During the past year, special induction motors have been designed and built for vertical irrigation pumps of the turbine or centrifugal type. These motors have hollow shafts through which the pump shafts project. The motor and pump shafts are connected by a clutch at the top of the motor. Important advantages are easy adjustment and alinement of the pump impeller, elimination of whipping action at the upper end of the pump shaft, or damage due to the momentary reversal of the motors during a power failure. Special windings obtain a low starting current when the motors are started at full line voltage. Relatively high starting and pull-out torques are obtained, with an efficiency and a power factor, at full load, approximately the same as those obtained with standard motors.

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## Synchronous Motors

In the report of last year, mention was made of the use of single-phase, synchronous motors as parts of motor-generator sets to be installed on railway locomotives for supplying d-c. power to the main traction motors. These sets have been made in three sizes,—400 k.w., 1000 k.w. and 2500 k.w.,—the ratings of the synchronous motor being 500 kv-a., 1200 kv-a., and 3100 kv-a., respectively,—25 cycles, 2300 volts, 750 rev. per min. These sets are equipped with direct-connected exciters and single-phase commutator motors, which are used not only for starting up the sets but also for furnishing excitation to the main traction motors for regenerative braking. For the purpose of maintaining uniform voltage at the terminals of the synchronous motors, the single-phase transformers for stepping the voltage down from 11000 to 2300 volts are provided with automatic tap changers. The two smaller sets are constructed with two bearings in the end shields while the large set has four bearings with the synchronous motor at one end and driving the two 1250 k.w. d-c. generators in tandem.

A new type of self-starting synchronous motor has been developed for use in time switches, traffic signals

Fig. 18—Double Propelling Motor for Diesel-Electric Tug Boat

and other small devices requiring very small amounts of power. It is similar to the ordinary induction disk motor which has a disk type rotor revolving between the poles of a stationary electromagnet. The synchronous characteristic is obtained by means of a series of small iron inserts pressed into the disk near the periphery, which locks into synchronism with the alternating flux. A motor of this type which is probably the smallest electric motor that was ever made for actual commercial use has been built. It is two inches high and weighs four ounces and its output is less than one-millionth h. p.

As has been mentioned in the 1925 report of this committee, two types of synchronous motor construction, particularly suitable for starting heavy loads, have been developed. One makes use of a built-in magnetic clutch which allows the rotor to come up to synchronous speed without load, the other is arranged so that the armature will be brought up to synchronous speed without load. For tube mills in cement manufacturing plants, there has been an active demand for motors of this type. The largest clutch-type motors have been

built during the year and are rated 900 h. p., 1800 rev. per min., 100 per cent power factor. A new competitor in this field is the synchronous induction type, of which an important example is mentioned in the induction motor section of this report.

High-speed, synchronous motors of the turbo-alternator type have been successfully used for gas pressure boosters and blowers. Motors of 1800 rev. per min. and 3600 rev. per min. have been built for this service. The largest motor of this type that has been built was put into operation this year and is rated 2700 h. p. at 180 rev. per min. It has successfully met the severe requirement of four starts in succession.

### D-c. Machines

The application of Diesel electric power for the propulsion of boats, particularly tug boats and ferries which require a very flexible control for maneuvering, has swung strongly in favour of d-c. machines. For this purpose, some special types of propelling motors have been developed which are designed to fit the cramped space available for them. These motors are constructed with double armatures. Motors of this type rated 1250 h. p. have been built for operation from a 1000-volt source. Normally the generating units are in pairs and their armatures are connected in series.

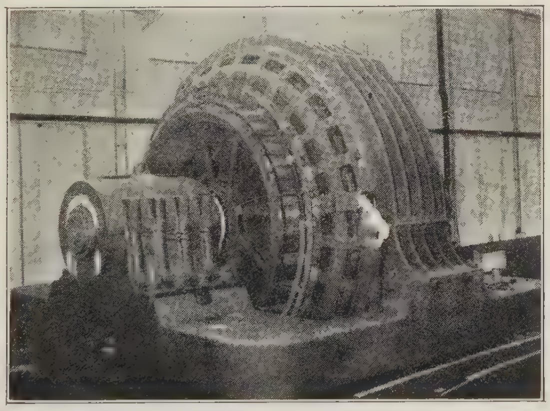

Fig. 19—8000-H. P. Direct-Current Motor for Driving the Largest Blooming Mill in the World
This is the largest single armature direct current motor.

As in the case of induction motors a new line of totally enclosed fan-cooled, d-c. motors has been developed. These motors have fans, external to the parts that enclosed the windings and core, which draw air into the end shields and blow it over the surface. This arrangement makes it possible to obtain greater outputs from a given frame size than it is possible with the ordinary type of enclosure. For certain slow-speed ratings it is possible to increase the rating as much as 50 per cent.

Hydroelectric units with large size d-c., generators in vertical shaft settings are quite unusual, and for this reason, the installation in a European power house of four 4500-kw. machines should be noted. These will be capable of delivering 12,300 amperes at pressures ranging from 175 volts to 350 volts. The normal speed is 500 rev. per min.

Although synchronous and induction motor drives in steel mills have made great advances, d-c. motors are found to have indispensable characteristics for certain applications and there seems to be a decided tendency to go back to d-c. motors for drives where variable speed is required. During the year there has been built and put into operation, a blooming mill drive with Ilgner motor-generator set and reversing motor capable of handling peak loads of 15,000 h. p. This apparatus embodies those features that have been found satisfactory in smaller units. During the past year work was completed on the 8000-h. p. d-c. motor which is to drive the largest blooming mill in the world. This is the largest single armature d-c. motor ever built, both as to continuous horse-power and maximum torque. Other installations are a 3000-h. p., 80/150-rev. per min., adjustable speed motor and a 7000-h. p., 50/100-rev. per min., adjustable speed motor.

The first steel mill motor, using the series exciter scheme of connection for obtaining flat speed regulation, was put into service during the past year. This speed regulation is obtained by using two field windings on the mill motor. One of these fields is supplied from a constant potential source while the other has for its source a separate exciter, the field of which is in series with the armature of the main machine. The series field can therefore be made to compensate for the tendency of the motor to drop its speed with increase of load.

A recent contribution to the study of limits of large d-c. machines places the maximum commutator segment voltage at 30 volts and the maximum peripheral speed of the commutator at 360 ft. per sec., but at speeds above 100 ft. per sec., difficulties due to unreliable brush pressure are encountered.

Two 1400-kw., 125-volt, 11,200-ampere, 360-rev. per min. generators, built during the past year to electrolytic refining service are the largest 125-volt machines that have been built to date. These machines are notable for the extremely high current delivered at low voltage by a single commutator.

As mentioned in another part of this report, one of the means of increasing the transient stability of a transmission system is by increasing the speed of response of the exciter. This increase in the response of the d-c. machine can be accomplished by any or all of the following means:

1. Dividing the exciter field circuit into parallel paths.
2. Separately exciting the d-c. machines.
3. Increasing the rotational speed of the exciter by separate drive.

The advantages of this type of exciter in increasing system stability are now very generally recognized. Many large machines sold during the past year have been supplied with the quick response exciters.

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## Mercury Arc Rectifiers

There have been no radical developments in mercury arc rectifiers during the past year. It has been the first year in which rectifiers have been in service in the United States in considerable numbers, and the first time that they have been used in steam railroad electrifications in this country. For the first time, such a length of main line has been fed from rectifiers that service of the road has been dependent upon their continuous operation. That this device is a dependable piece of apparatus is indicated by the fact that a 1500-kw., 1500-volt rectifier has carried peak loads of 9000 kw. during an emergency extending over a period of several weeks.

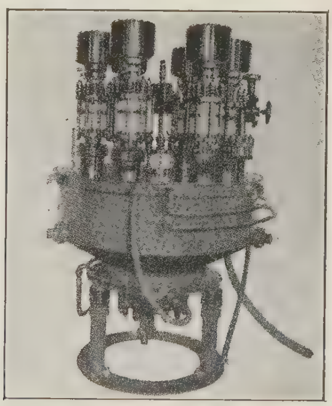

Fig. 20—Steel-Tank Mercury Arc Rectifier Rated 500 Kw., 600 Volts, or 750 Kw., 1500 Volts

It has been observed that inductive interference may be experienced in some cases of mercury arc rectifier operation but this problem has been met and methods have been worked out to bring the performance within communication standards.

A new type of rectifier has been placed on the market which has a higher current capacity than any built heretofore. This machine has twelve anodes and has a continuous rating of 2000 amperes at 600 volts. At higher voltages the current rating is a little less. Further progress has been made in the development of rectifiers for high voltages. Successful load tests have been made on steel cased units at 8000 volts. The application of power rectifiers of such high voltage is, at present, confined to certain chemical processes. Its overall efficiency is approximately 99 per cent. The voltage of rectifiers suitable for railway work is limited at present only by the design of the motor equipment. The total capacity of rectifiers installed by one large European manufacturer during the past year amounts to about 200,000 kw. and 90 per cent of them are for railway work.

Probably the most outstanding installation of rectifiers in the United States is that for the electrification of the Illinois Central Railroad terminal and suburban service at Chicago, where 9000 kw. in rectifier capacity is in use. An indication of the European confidence in rectifiers is made manifest in the placing of orders for a total of 95 units having a total capacity of 114,000 kw. by the Metropolitan railroads of Berlin.

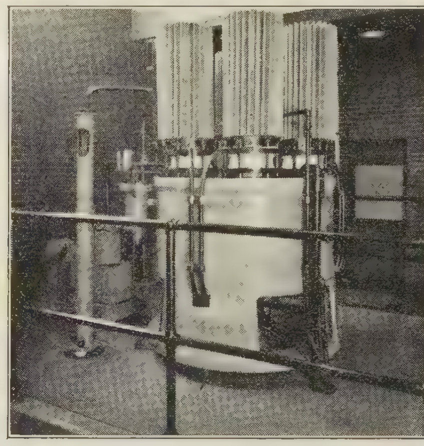

Fig. 21—View of Mercury Arc Rectifier of American Manufacture with Complete Equipment

During the past two years the total capacity of rectifiers manufactured and installed the world over has doubled each year.

In 1924 the total capacity was approximately 150,000 kw. In 1925 it increased to 310,000 kw., and in 1926 to 600,000 kw.

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## Diesel Engine Driven Alternators

During the year, the largest Diesel engine driven generator has been put into operation at Hamburg (Germany). The engine is rated at 15,000 h. p. and is of the two-stroke cycle type with nine double acting cylinders. The direct-connected alternators are rated 13,000 kv-a., 94 rev. per min., 6000 volts, 50 cycles. The design of the shaft and coupling of a unit of this kind requires the consideration of torsional oscillations of the shaft.

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## Frequency Converters

Ties between power systems of the same frequency permitting control of the flow of power in either direction under conditions of varying voltage are made possible by the use of transformers having taps that may be changed under load and it is also possible to tie two systems of different frequency and control the flow of power under conditions of variations in frequencies by frequency converters of the induction type. This type of converter, consisting of a synchronous machine and an induction machine with Scherbius control, was mentioned in the report of this Committee in June 1925. A number of 5000-kw. sets of this description have been built. Another type of converter makes use of the cascade induction motor which depends upon a constant ratio of frequency. A number of 35,000- and 40,000-kw. sets of this type have been previously noted. During the past year there has been built a 15,000-k. w. set of this description, and a 35,000-kw. synchronous frequency converter set has been arranged with suitable spring support for the generator stator so that it can be used for single-phase operation. This type of support minimizes the effect of the pulsating torque resulting from single-phase operation. The single-phase rating is 21,000 kv-a. The largest synchronous frequency converter set ever built has been put into operation. It is rated 50,000 kv-a., 300 rev. per min.

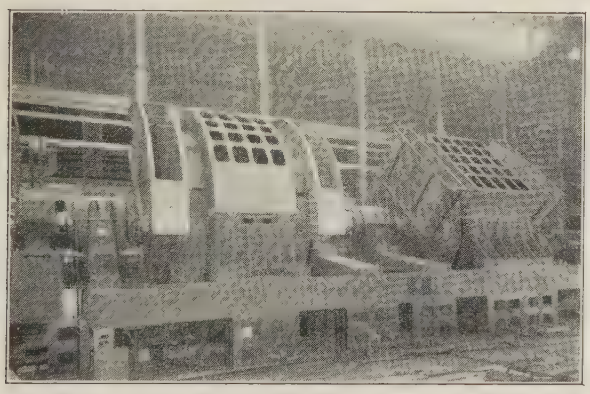

Fig. 22—Shop View of 30,000-Kv-a., 600-Rev. per min. Frequency Converter Set
Showing Arrangement of air intake and exhaust

Two sets with unusually high speed, have been built in the past year; one, a 30,000-kv-a. frequency changer at 600 rev. per min., and the other, a 17,777-kv-a. set at 720 rev. per min. The 30,000-kv-a. set is a 50-cycle—60-cycle set. The 50-cycle machine has been designed particularly for transmission line stability and incorporated in it the features described under the heading *Machine Characteristics for Stability.*

In Europe there has been an increased demand for synchronous frequency converters principally for railway work.

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## Synchronous Condensers

Because of the fact that synchronous condensers are in the class of non-revenue producing equipment, there has been a concerted effort to reduce costs and losses. This has been accomplished partly by designing for higher speeds. Sixty-cycle condensers have been constructed for operation at 900 rev. per min. up to a 10,000-kv-a. capacity and at 720 rev. per min. up to 20,000 kv-a. The largest condensers yet constructed are several that are for use for the regulation of the voltage at the receiving end of a 220-kv. transmission line in California. They are rated 50,000 kv-a., 600 rev. per min., 50 cycles, and the total calculated losses are only 1 2/3 per cent. They will be provided with a closed system of ventilation.

The largest condenser ever arranged for automatic control is under construction. It is rated 30,000 kv-a.

In Europe it is being found advantageous to employ as condensers asynchronous machines provided with phase advancers. A number of these have given complete success in service. They have been built in capacities up to 10,000 kv-a. Mention of these machines is made on p. 183 of the *Electrotechnische Zeitschrift* for February 10th, 1927.

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### Sine-Wave Generators

The largest sine-wave testing generator has been completed during the year. It is rated 2000 kv-a., 2300 volts, 3-phase, 60 cycles, 1200 rev. per min., and is driven by a 600-kv-a., synchronous motor. This generator is capable of delivering 1200 kv-a., single-phase, and it is remarkable in that the voltage and current wave forms are sine-waves under all conditions of load. The characteristics are practically ideal. This set was built for use in testing high-voltage, underground cables.

### High-Frequency Machines

During the past year a plan for the resonant control of street lights has been developed and this should give a new field for the application of high-frequency machines. This system of control requires a generating system which can supply both 440 and 660 cycles to the main lighting circuit. The entire system is described in the *Electric Journal* for February 1927.

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### Induction Voltage Regulators

An improvement in the design of induction regulators for outdoor service has been made by bringing the driving spindle for the movable element out through one of the passages connecting the regulator tank and the expansion vessel, thus avoiding the use of all glands. An improvement in operation of induction voltage regulators as affecting vibration and noise has resulted from the use of roller bearings for the lower end of the shaft. A clearance in sleeve bearings will allow the movable element to vibrate and cause noise, yet tight bearings are liable to stick and interfere with the operation. Roller bearings can at once be made tight and free to turn. The use of all-welded, corrugated sheet-iron tanks has resulted in improved appearance, reduced weight, increased insurance against leakage and greater ability to withstand shocks as compared with the corrugated cast-in construction.

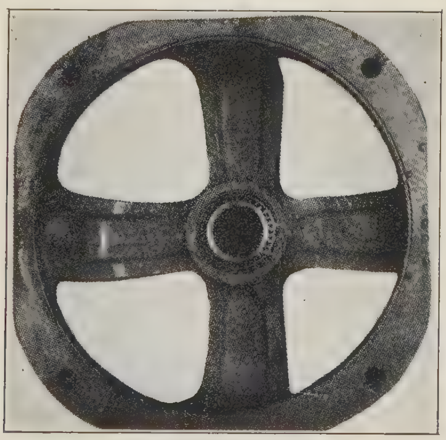

Fig. 23—Arrangement of Lower Bearing of Tapered Roller Type for Induction Voltage Regulator

### Synchronous Converters

During the year, some synchronous converters have been built which have an unusually wide range of direct current voltage. They are rated at 1500 amperes over a range of 87 to 175 volts. The method of obtaining this variation in voltage is unique in that the a-c. voltage at the collector rings is varied by means of tap changing on the transformer. It is necessary, of course, to change the field excitation to correspond to the different transformer taps. Voltage variation between taps is obtained by field control.

The twelve phase synchronous converter which was mentioned in the report of last year has been put into operation and two more have been built. The various advantages which were mentioned have been fully realized in actual practise and it is not improbable that for future production the number of 12-phase converters will exceed that of six phase.

A recent English development in synchronous converters is the socalled binary converter, which in effect is a device consisting of an induction motor and a special direct current generator having a common magnetic circuit of sufficient size to take care of both rotating and stationary fluxes. This machine consists of a uniform magnetic circuit and a rotating armature. Two windings are located in the same slots of the stationary member, one for producing the stationary current flux and the other for producing a rotating flux. By a combination of a two-pole a-c. winding and a six-pole d-c. winding the six-pole d-c. winding on the rotating armature acts as a short circuit or squirrel cage winding for the bipolar a-c. winding. The usual commutator and brush gear is used with the armature winding.

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B. L. BARNS, *Chairman* of Subcommittee on Annual Report.

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Science has learned that the ultra-violet rays in sunlight are beneficial in curing various sorts of human ailments. But since their wave-lengths are so short as to make this light invisible, there has been great difficulty in determining how much of this light there was in sunshine from day to day or from hour to hour even though the sunshine appeared uniform. An electrical radiometer has been perfected by Dr. Pettit, a government scientist, working at the Solar Observatory in Pasadena, Cal. This makes a written record every day of the ultra-violet content of sunlight. This device is coming into use by hospitals where the curative value of sunshine is used.

# Electromagnetic Waves Guided by Parallel Wires
## With Particular Reference to the Effect of the Earth

BY S. A. LEVIN*

Associate, A. I. E. E.

*Synopsis.—A theory of the propagation of electromagnetic waves guided by a system of parallel wires is developed with particular reference to the effect of the earth, and is simplified so that it is identical in form with the elementary theory.*

*Important general properties of a system of parallel conductors and their application to problems of propagation in power or communication circuits, or in a system of both types of circuits, derived by Professor Pleijel from the elementary theory, are mentioned together with several remarks of practical importance. The simplified theory leads to the same conclusions and, consequently, to the same applications.*

*The simplified theory gives promise of successful application to such problems of propagation in transmission systems which heretofore as a rule have not been formulated with sufficient precision.*

### Introduction

For the propagation of electromagnetic waves along any number of parallel wires of any configuration, mainly the elementary theory[1,2,3] has been employed†. Usually the earth is considered as very remote or as a perfect conductor. Rigorous theories have been developed in special cases for conductors in free space, as well as with proper regard to the influence of the earth. Earlier literature is found in reference 4; some recent work is mentioned in references 5 to 17, inclusive. A theory of propagation on a system of parallel wires, with particular reference to the effect of the earth, is developed in the theoretical part of this paper. To make this theory practically applicable, certain assumptions are made in the discussion. The simplified theory is identical in form with the elementary theory.

In a paper based upon the elementary theory Professor Pleijel[18] has derived general properties of a system of parallel wires and pointed out their application to several problems connected with the propagation of electromagnetic waves along power or communication circuits, or systems of both. The section of the present paper dealing with applications of the theory shows that these properties and their applications follow also from the simplified theory mentioned above and, in addition, contains remarks of practical interest.

It is believed that the simplified theory will permit application to many of those problems regarding electromagnetic wave propagation in transmission systems which previously often were not formulated with a sufficient degree of accuracy.

### Theory

Consider $v$ wires of circular cross-section parallel to the $z$-axis, (see Fig. 1). Let the $x$ $z$-plane separate the two media $A$, the air, and $B$, the earth. The conductors may be located in one or both of these media. Some may be of copper, some of iron, or any other material. All the conductors in the earth must be insulated. In the air, some or all of them may be covered with insulation. Some conductors may be arranged so as to correspond to a cable, but some of the following considerations do not strictly apply to such an arrangement. The conductors, the media $A$ and $B$, and the

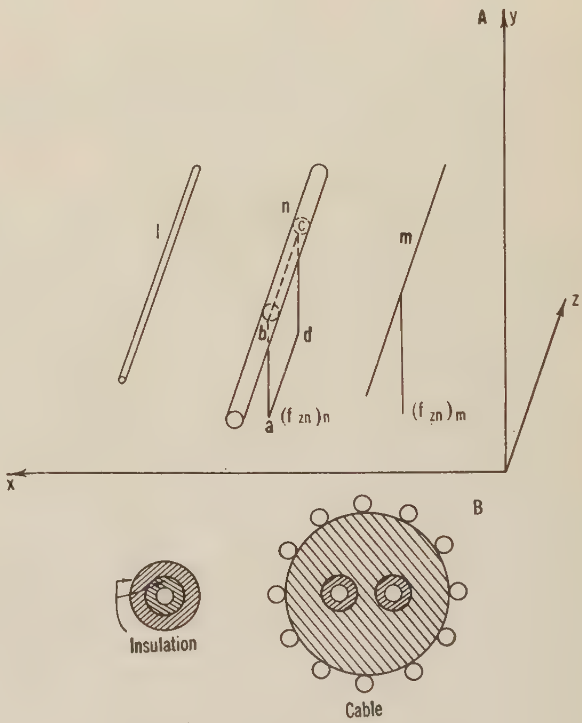


Fig. 1

insulating materials are supposed to be homogeneous and isotropic.

The separations between the conductors, and their distances from the surface of the earth, are supposed to be so large compared to the radii of the wires that the electromagnetic field inside each wire is symmetrical about the axis of the wire. The insulation of the wires is supposed to be so thin that it can be neglected. The fundamental assumption is that at a given frequency $f$

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1. See references at end of article.

†See reference 21. This paper, however, was not known to the author when the present theory was developed.

*Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 21-24, 1927.*

the electromagnetic state* of the system can be represented, except at the ends, by a number of traveling waves. Only one of them with the propagation constant $\Gamma$ will be considered, unless otherwise specified. The components of the corresponding electric and magnetic field vectors, $F$ and $H$, respectively, are the real parts of the complex expressions, obtained by multiplying

$$F_x(x, y),\ F_y(x, y),\ F_z(x, y),\ H_x(x, y),\ H_y(x, y),\ H_z(x, y)$$

by the exponential factor $e^{-\Gamma z + j\omega t}$ where $t$ is the time, $\omega = 2\pi f$ and $j = \sqrt{-1}$. The factors $F_x$, etc., are represented by different analytical expressions inside each wire, in the air, and in the earth. They satisfy the boundary conditions at the surfaces of the wires and at the surface of the earth.

Regarding the justification of the assumption of a field with the components

$$F_x\,(x, y)\, e^{-\Gamma z + j\omega t} \quad . \quad . \quad . \qquad (\mathbf{A})$$

the following may be noted: Considering first the simple case of a single conductor of circular cross-section in free space, it has been shown by Sommerfeld[22] and Hondros[23] (see also references 24, 25, and 26 for other important contributions) that there are several fields each of the form (**A**) which satsify the physical requirements; *i. e.*, Maxwell's equations and the conditions at the boundary and at infinity. Some of these fields are rejected for physical reasons. The remaining fields may be termed physical fields. Only experiment can decide if one or several of the physical fields actually can exist since the physical requirements do not determine the field uniquely. Experiment shows the observed field is equal to one of the physical fields, "the main wave." Thus, at least for the present purpose, it is unimportant whether or not there can exist the remaining physical fields, "the secondary waves," or any other field satisfying the physical requirements but not included among the main and secondary waves found by Sommerfeld and Hondros. Hondros has shown that the secondary waves are so strongly damped that they cannot be detected even if they exist. Reverting to the general case of a system of parallel cylindrical conductors, it may be expected that there are several fields, each of the form (**A**), satisfying the physical requirements, and that some of these fields are physical fields. Experiment may be expected to show that the observed field is equal to a field which is the resultant of certain of the physical fields, "the main waves." It may not be important to attempt a proof of these expectations if a number of fields are found which approximately satisfy the physical requirements and adequately account for the phenomena observed.

The $z$-component of the electric current in the wire $n$ equals $\int \gamma_n F_z\, d\, s$ multiplied by $e^{-\Gamma z + j\omega t}$.

*Due to sinusoidal electromotive forces, of the frequency $f$, at the conductor terminals when the steady state is attained.

Let

$$\int \gamma_n F_z\, d\, s = I_n \qquad (1)$$

Hereafter the exponential factor $e^{-\Gamma z + j\omega t}$ will be omitted for the purpose of simplification. The conductivity of the wire is $\gamma_n$. The integral is extended over the cross-section of the wire, and its value, $I_n$, is independent of the location of the cross-section along the wire. The electromagnetic field everywhere outside the wires, *i. e.*, in the air and in the earth, would be the same as the field that would be produced there by currents $I_n$ concentrated at the axes of the wires, if each wire were removed and replaced by the medium surrounding it. Consider an element of the concentrated current $I_n$. It produces an electromagnetic field that satisfies Maxwell's equations at all points in space and also satisfies the boundary conditions at the surface of the earth.[19] The same is true for the resultant field produced by any combination of elements. Let $F_n$, $H_n$ be the vectors of the electromagnetic field produced outside the wires by all the elements of the current $I_n$ alone. The components of these vectors are $F_{xn}\,(x, y)$, etc., multiplied by the exponential factor. The component $H_{zn}$ can be neglected.† This permits of the definition of single-valued electric voltages and magnetic fluxes. Maxwell's equations are (elm. c. g. s. units),

$$\left.\begin{aligned} \operatorname{curl} H_n &= 4\pi\gamma F_n + K\frac{\partial F_n}{\partial t} \\ \operatorname{curl} F_n &= -\mu\frac{\partial H_n}{\partial t} \end{aligned}\right\} \qquad (2)$$

where the constants

$\gamma$ = conductivity
$K$ = dielectric constant
$\mu$ = permeability

have different values in the air and the earth. It follows from these equations and $H_{zn} = 0$ that

$$\left.\begin{aligned} F_{xn} &= \frac{\Gamma}{4\pi\gamma + j\omega K}\,\frac{1}{\alpha}\,\frac{\partial F_{zn}}{\partial x} \\ F_{yn} &= \frac{\Gamma}{4\pi\gamma + j\omega K}\,\frac{1}{\alpha}\,\frac{\partial F_{zn}}{\partial y} \\ H_{xn} &= -\frac{1}{\alpha}\,\frac{\partial F_{zn}}{\partial y} \\ H_{yn} &= \frac{1}{\alpha}\,\frac{\partial F_{zn}}{\partial x} \end{aligned}\right\} \qquad (3)$$

where

$$\frac{\partial^2 F_{zn}}{\partial x^2} + \frac{\partial^2 F_{zn}}{\partial y^2} = (4\pi j\omega\mu\gamma - \omega^2\mu K - \Gamma^2)\, F_{zn}$$

and (4)

†See, for instance, reference 21.

$$\alpha = \frac{4\,\pi\, j\, \omega\, \mu\, \gamma - \omega^2\, \mu\, K - \Gamma^2}{4\,\pi\,\gamma + j\,\omega\, K} \tag{5}$$

The field is proportional[19] to $I_n$.

Let

$$F_{zn} = f_{zn}\,(x, y)\; I_n \tag{6}$$

The function $f_{zn}$ satisfies equation (4) and consequently contains $\Gamma^2$. It is represented by different expressions in the air and in the earth, but it is continuous at the surface of the earth. For a given wire $n$ the same expressions apply for all waves. Thus, two waves on the same wire with different values of $\Gamma^2$ give different values of $f_{zn}$ only because the $\Gamma^2$ values are different. This will be expressed by saying that $f_{zn}$ depends upon $\Gamma^2$. The value of $f_{zn}$ at the $x\,z$-plane vertically below (or above) wires $n$ and $m$ is $(f_{zn})_n$, and $(f_{zn})_m$, respectively, see Fig. 1.

The $z$-component of the total electric field at the surface of wire $n$ is

$$z_n\; I_n \tag{7}$$

where $z_n$ is the internal impedance of the wire and is practically independent of $\Gamma^2$.

The magnetic flux per unit length through the loop $a\,b\,c\,d$, see Fig. 1, due to $I_n$, equals

$$\int_o^{h_n} \mu\, H_{zn}\, d\,y = \int_o^{h_n} - \frac{\mu}{\alpha}\,\frac{\partial f_{zn}}{\partial\, y}\; I_n\, d\,y = (\phi_n)_n\, I_n \tag{8}$$

where $h_n = a\,b$ is the distance from the surface of the wire to the $x\,z$-plane, counted positive when the wire is above the $x\,z$-plane. The flux per unit length through the loop due to $I_m$ is

$$\int_o^{h_n} \mu\, H_{zm}\, d\,y = \int_o^{h_n} - \frac{\mu}{\alpha}\,\frac{\partial f_{zm}}{\partial\, y}\; I_m\, d\,y = (\phi_m)_n\, I_m \tag{9}$$

Both $(\phi_n)_n$ and $(\phi_m)_n$ depend upon $\Gamma^2$.

The voltage to ground of wire $n$ equals,

$$\int_{h_n}^{o} F_y\, d\,y = \int_{h_n}^{o} \frac{\Gamma}{4\,\pi\,\gamma + j\,\omega\, K}\,\frac{1}{\alpha} \sum_{n=1}^{v} \left(\frac{\partial f_{zn}}{\partial\, y}\; I_n\right) d\,y$$
$$= V_n \tag{10}$$

The usual application of the second equation of (2) gives

$$\Gamma\, V_n = Z_{nn}\, I_n + \sum_{m \neq n} Z_{mn}\, I_m \tag{11}$$

where

$$\left.\begin{aligned} Z_{nn} &= z_n - (f_{zn})_n + j\,\omega\,(\phi_n)_n = R_{nn} + j\,\omega\, L_{nn} \\ Z_{mn} &= -\,(f_{zm})_n + j\,\omega\,(\phi_m)_n = R_{mn} + j\,\omega\, L_{mn} \end{aligned}\right\} \tag{12}$$

All terms in (12) depend upon $\Gamma^2$. $Z_{nn}$ is the self-impedance of wire $n$. $Z_{mn}$ is the mutual impedance between wires $m$ and $n$ when $m$ carries the current. $R_{nn}$ ($L_{nn}$) is the self-resistance (inductance). $R_{mn}$ ($L_{mn}$) is the mutual resistance (inductance) when $m$ carries the current. All impedances are per unit length.

If $(V)$ and $(I)$ are the vector voltage and current, respectively, as they are understood in ordinary a-c. theory, it follows from equation (11) that

$$-\frac{\partial\,(V_n)}{\partial\, z} = Z_{nn}\,(I_n) + \sum_{m \neq n} Z_{mn}\,(I_m) = \sum_{m=1}^{v} Z_{mn}\,(I_m) \tag{13}$$

Briefly, this is explained as follows. Note that all quantities in equation (11) are complex quantities. Put $V_n = V_{n1} + j\, V_{n2}$, etc. Multiply equation (11) by $e^{-\Gamma z + j\omega t}$, calculate the real parts of the expressions on both sides of the equality sign and put them equal to each other. The equation thus obtained will contain two expressions on the left side of the equality sign, each containing a factor one of which is the time-derivative of the other. A similar remark applies to the expression to the right of this sign. It is seen that the equation gives a relation between the instantaneous voltage and current values which are the real parts of $V_n\, e^{-\Gamma z + j\omega t}$, etc., so that the vector expression on the right in equation (13) equals the vector $\Gamma\,(V_n)$. Finally, the derivative with respect to $z$ of the instantaneous voltage shows that the vector relation $\Gamma\,(V_n) = -\dfrac{\partial\,(V_n)}{\partial\, z}$ is true.

From the usual application of the fact that the divergence of the sum of the conduction and displacement current is equal to zero, it follows that

$$\Gamma\, I_n = 2\,\pi\, r \left(\gamma + \frac{j\,\omega\, K}{4\,\pi}\right) F'$$

where $r$ is the radius of the conductor $n$ and $F'$ the component, normal to the surface of the conductor, of the total electric field immediately outside this surface. The total leakage current from the conductor per unit length is $2\,\pi\, r\,\gamma\, F'$. The total electric charge on the conductor per unit length is $2\,\pi\, r\,\dfrac{K}{4\,\pi}\, F'$. The intersection between a plane $z$ = constant, the surfaces of the conductors, and the surface of the earth consists of a number of circles and a straight line. The voltage on each circle is constant. If, as an approximation, the voltage on the line is assumed constant, it follows by comparison with familiar electrostatic methods* that

$$\Gamma\, I_n = \sum_{m=1}^{v} \beta_{mn}\, V_m$$

where $\beta_{mn} = \beta_{nm}$ and both are complex coefficients independent of $\Gamma^2$. Consequently

$$-\frac{\partial\,(I_n)}{\partial\, z} = \sum \beta_{mn}\,(V_m) \tag{14}$$

Equation (14) can also be written

$$-\frac{\partial\,(I_n)}{\partial\, z} = (A_{nn} + j\,\omega\, C_{nn})\,(V_n) +$$

*Neglecting[7], in the dielectric, $\Gamma\, F_z$ in div. $F = 0$.

$$\sum_{m \neq n} (A_{mn} + j\,\omega\, C_{mn})\,[\,(V_n) - (V_m)\,] \qquad (15)$$

where the coefficients $A$ and $C$ are the leakages and capacities per unit length, respectively.

If

$$Z_{mn} = Z_{nm} \qquad (16)$$

then

$$\left.\begin{aligned} R_{mn} &= R_{nm} \\ L_{mn} &= L_{nm} \end{aligned}\right\} \qquad (17)$$

Since

$$\beta_{mn} = \beta_{nm} \qquad (18)$$

thus

$$\left.\begin{aligned} A_{mn} &= A_{nm} \\ C_{mn} &= C_{nm} \end{aligned}\right\} \qquad (19)$$

The general validity of equation (16) has not been investigated here.[15] In the following case the equation holds. In Fig. 1 let $n = 2$. The flux per unit length through the loop $a\,b\,c\,d\,a$ due to the current $I_1 = 1$ is

$$(\phi_1)_2 = \int_0^{h_2} - \frac{\mu}{\alpha}\,\frac{\partial f_{z1}}{\partial y}\, d\,y$$

The voltage to ground at wire 2 due to $I_1 = 1$ is

$$V = \int_{h_2}^{0} \frac{\Gamma}{4\,\pi\,\gamma + j\,\omega\,K}\;\frac{1}{\alpha}\;\frac{\partial f_{z1}}{\partial\, y}\; d\,y$$

Let $f_{z1}\,(h_2)$ represent the value of the function at the surface of wire 2. The second equation of (2) gives

$$f_{z1}\,(h_2) - (f_{z1})_2 = \frac{\Gamma^2}{(4\,\pi\,\gamma + j\,\omega K)\mu}\;(\phi_1)_2 - j\;\omega\;(\phi_1)_2$$

If $\Gamma = 0$, then

$$f_{z1}\,(h_2) = -\,Z_{12}$$

*i. e.*, the $z$-component of the electric field at the wire 2 due to $I_1 = 1$ equals the negative value of the mutual impedance. The $z$-component of the electric field at the wire 1 due to $I_2 = 1$ equals

$$f_{z2}\,(h_1) = -\,Z_{21}$$

But[14] when $\Gamma = 0$

$$f_{z1}\,(h_2) = f_{z2}\,(h_1),$$

This relation is also true[20] when $\Gamma \neq 0$. Thus, when $\Gamma = 0$, equation (16) holds irrespective of the location of the wires.

It can easily be shown that all previous considerations can be extended to the case where the insulation of the wires has finite thickness and the space below the $x\,z$-plane is occupied by layers of different homogeneous and isotropic materials, provided no conductor is close to the surface separating two such layers. For instance, immediately below the $x\,z$-plane there may be a layer of water followed by a layer of earth, and so forth.

## Discussion of Theory

Consider equations (13) and (14) or (15) for a given wire $n$. Write down all equations (13), one for each $\Gamma$, also all equations (14). If the corresponding coefficients in equations (13) and the corresponding coefficients in equations (14) were all equal, the addition of equations (13) and the addition of equations (14) show that these equations apply to the total values of the voltages and currents. The coefficients in (12) are, however, unequal for all waves with unequal values of $\Gamma^2$. The equations do not apply strictly to the total values of the voltages and currents, except in the case when only two waves exist with the propagation constants $\Gamma$ and $-\Gamma$. For most practical purposes it will be necessary to make an approximation.

The approximation mentioned consists in the use of equations (13), (14) and (15) in which the vectors denote total values, and equation (16), it being understood that it is desirable to determine experimentally the limitations of such a procedure. The equations are then identical in form with the equations of the elementary theory. The present theory represents an advance, at least in so far as the effect of the finite conductivity of the earth manifests itself in the coefficients. The theory gives a physical picture of the phenomena occuring in the conductors and in space.

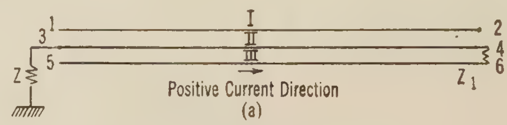


Fig. 2A

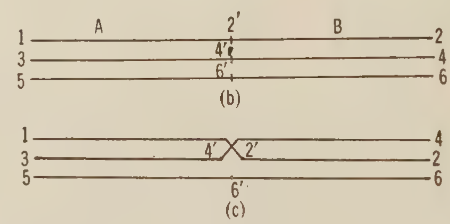


Fig. 2B, 2C

It also points out the approximations involved in the elementary theory.

## Some Applications of the Theory

Let 1, 2, 3, 4, etc., denote the ends of wires, I, II, III, etc., see Fig. 2A. The total vector voltage to ground and the current at 1 will be denoted by $v_1$ and $i_1$, respectively, and so on. It follows[18] from equations (13) and (15) that

$$\left.\begin{aligned} v_1 &= b_{11}\,i_1 + b_{12}\,i_2 + b_{13}\,i_3 + b_{14}\,i_4 + \ldots \\ -\,v_2 &= b_{21}\,i_1 + b_{22}\,i_2 + b_{23}\,i_3 + b_{24}\,i_4 + \ldots \\ v_3 &= b_{31}\,i_1 + b_{32}\,i_2 + b_{33}\,i_3 + b_{34}\,i_4 + \ldots \\ -\,v_4 &= b_{41}\,i_1 + b_{42}\,i_2 + b_{43}\,i_3 + b_{44}\,i_4 + \ldots \end{aligned}\right\} \qquad (20)$$

etc.

where the coefficients $b_{nm} = b_{mn}$ are composed of the coefficients in equations (13) and (15) in a complicated way. Since the line is uniform throughout its length, it follows[18] that

$$\left.\begin{array}{lll} b_{11} = b_{22} & b_{31} = b_{42} & \\ b_{13} = b_{24} & b_{32} = b_{41} & \text{etc.} \\ b_{14} = b_{23} & b_{33} = b_{44} & \\ \cdot & \cdot & \\ \cdot & \cdot & \\ \cdot & \cdot & \end{array}\right\} \quad (21)$$

Let $A$ and $B$ be two sections, see Fig. 2B, such that equations (**20**) and (**21**) apply to each of them but with constants $b$ differing on account of changes in the earth conductivity, the geometry of the system, and so forth. The changes in the geometry may be due to transpositions, see Fig. 2C, different spacings, different distances from the ground, etc. There will be a relation (**20**) between the quantities at 1, 3, 5 and at 2′, 4′, 6′. A similar relation will hold between the quantities at 2′, 4′, 6′ and at 2, 4, 6. Eliminating the quantities at 2′, 4′, 6′ gives equation (**20**) where $b_{nm} = b_{mn}$, but equation (**21**) no longer holds. If several sections are added in this way, the result is always equation (**20**) with $b_{nm} = b_{mn}$.

Let $A$, Fig. 2D, be a system, composed of one or several sections. At one end of the system are impedances $Z_1$ and $Z_2$ (*e. g.*, loading coils); they may also have a mutual impedance $Z_{12}$ (*e. g.*, booster transformer). One wire may be grounded through an impedance $Z$ (*e. g.*, ground wire). Between the quantities at 2″, 4″, 6″ and at 2, 4, 6, a relation (**20**) holds, which together with

$$\left.\begin{array}{l} v_2' = v_2'' \\ i_2' = i_2'' + \dfrac{v_2'}{Z} \\ i_4' = i_4'' \text{ and } i_6' = i_6'' \\ v_4' = v_4'' + Z_1 i_4' + Z_{12} i_6' \\ v_6' = v_6'' + Z_2 i_6' + Z_{12} i_4' \end{array}\right\}$$

permits the elimination of the quantities at 2″, 4″, 6″. The result is equation (**20**) between the quantities at 2′, 4′, 6′ and at 2, 4, 6 where now some of the coefficients $b$ will contain $Z_1$, $Z_2$, $Z$, etc., but still remain such that $b_{mn} = b_{nm}$. If the system $A$, including its equipment of terminal impedances $Z_1$, $Z_2$, $Z$, etc., is connected to another system $B$, see Fig. 2D, the result is still equation (**20**).

If a transformer is connected as shown in Fig. 2E, it is easy to show that there is not a sufficient number of equations to permit the elimination of the quantities at 2′, 4′. Equation (**20**) does not apply in such a case.

If necessary, divide a system into sections so that equation (**20**) applies to each section. The terminal conditions of such a section will now be considered. The wires may be interconnected at the ends, ground connections may also be used. For instance, the point 3, Fig. 2A may be grounded through an impedance $Z$. Then

$$v_3 = -\, i_3 (Z + R)$$

where $R$ is the ground resistance of the grounding device. This resistance is included to correct, at least approximately, the conditions at the ends of the system where the considerations of the paper do not strictly apply. This resistance $R$ also should be included in $Z$ in Fig. 2D. If the points 4 and 6, see Fig. 2A, are connected by an impedance $Z_1$, then

$$i_4 = -\, i_6,\; i_4 Z_1 = v_4 - v_6$$

and so forth. In this connection the following may be noted, see Fig. 2A. The wires I, II, III, may continue to the right of the points 2, 4, 6. The system to the right is then the termination of wires I, II, III at these points.

It is possible to determine the coefficients $b$ in equation (**20**) by experiment.[18] These equations are of fundamental importance and, together with their consequences, permit of important applications.[18] At first sight the great number of coefficients to be determined would seem to hinder applications, except when the number of wires is small. Fortunately this is not the case. It is possible, for instance, in a lead containing a large number of wires, to study the currents and the voltages to ground at the ends of one wire, or the currents and the voltages between two wires at the ends of a loop of these two wires, by measuring only a few coefficients. This has been shown in a few cases,[18] which correspond, for instance, to the propagation of voltage and current along a single telephone wire, or a loop of two wires, from the end $A$, see Fig. 2F, of an exposure between power and communication circuits to a point $B$, where the currents and the voltages may be of interest. There are also other cases when a study can be made by measuring relatively few coefficients, as can easily be shown by methods similar to those employed in the paper referred to.[18] Thus, for instance, the voltages and the currents induced in a single wire or a loop of two wires in a lead can be studied by comparatively few measurements.

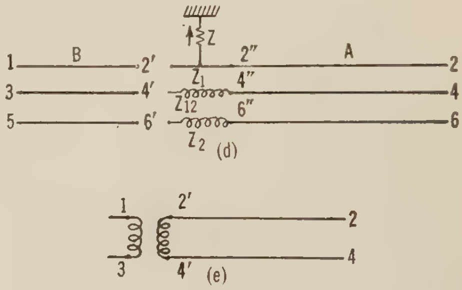


FIG. 2D, 2E

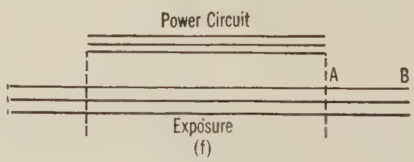


FIG. 2F

In conclusion, some remarks will be made regarding

the application of equation (**20**) to problems of inductive coordination between power and communication circuits.

It is customary and useful to distinguish between uniphase and balanced currents and voltages on a power system and consider the induction on a telephone system due to them separately. It is seen that the coefficients $b$ are applicable both to uniphase and balanced induction. Once the uniphase and balanced components are known in magnitude and phase at the ends, the inductive effects can be found by using the same coefficients $b$. It is not necessary to use separate coefficients for balanced and uniphase induction. This facilitates experimental work and analysis considerably.

The impedances of loading coils, booster transformers, etc., appear in the coefficients $b$, as seen above. The effect of the line proper can be determined, if all these devices are short-circuited. If the coefficients are then determined with these devices their influence can be found.

The coefficients have to be determined at different frequencies. At a given frequency they will, presumably, depend upon the current density when iron is present in the circuits.

It is possible to calculate the coefficients $b$ for a simple system, assuming the earth to be a perfect conductor, or very remote. If the coefficients are measured the comparison between the measured and calculated coefficients gives an idea of the effect of the earth.

The irregularities in the geometry of the system, in the earth's conductivity, and so on, appear in the coefficients $b$, determined experimentally. This is of very great importance, particularly for the voltages between two neighbouring wires. If, as is often done, their voltages to ground are calculated by some method, even of great accuracy, then the difference between these two calculated voltages which are usually fairly large is not equal to the actual voltage between the wires, usually fairly small, since even small errors due to irregularities of the system in the voltages to ground give a large error in their difference.

## Conclusions

A theory of propagation of electromagnetic waves guided by parallel wires with regard to the effect of the earth has been developed. The theory shows how the finite conductivity of the earth enters into the problem of propagation. It also gives an idea of the physical phenomena involved. The approximations necessary for the development of a simplified theory suitable for engineering applications have been pointed out. Some applications of the simplified theory to transmission systems for power and communication purposes, suggested by Professor Pleijel, have been indicated, together with remarks of practical interest.

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# Discussion at Pittsfield

## CHANGING TAPS ON TRANSFORMERS UNDER LOAD[1]

(Hill)

## CHARACTERISTICS OF INTERCONNECTED POWER SYSTEMS AS AFFECTED BY TRANSFORMER RATIO CONTROL

(Blume)

## LOAD RATIO CONTROL EQUIPMENT[3]

(Palme)

Pittsfield, Mass., May 26, 1927

**E. F. Gehrkens:** The subject of voltage control is an exceedingly important one and it was so recognized as far back as 1882, at which time an automatic generator voltage regulator for d-c. machines was developed.

When the a-c. system was introduced and large generating units were built, two types of *feeder* voltage regulators were developed,—the switch or step type and the induction type.

Each design has its advantages and disadvantages, and in order to eliminate the disadvantages so far as possible, as long ago as 1898, a combination of the two was designed and built for the control of electric furnaces.[3]

This combination is justified only in case large regulating units are required, and the delay in the development in this design was due partly to the lack of sufficient demand to warrant the expense and to difficulties of design; for although the theory and connection diagram are simple, the mechanical design is extremely difficult. Previous to 1898 induction regulators having capacities of 700 kw. were also built for the same purpose and while the latter was the more simple in design and operation, the former was less expensive and more efficient with a better power factor.

For lighting systems requiring relatively small regulators, the induction type is the recognized standard because of its simplicity and low cost, but for power and interconnecting lines requiring large regulators, the selection of the regulator depends upon the requirements and the cost. In design, the induction type is limited to approximately 13,000 volts, and for use on higher-voltage systems it requires an exciting and a series insulating transformer. This increases the cost and the losses. The switch type can be built for use in much higher voltage circuits and therefore has the advantage.

In the combination of the switch and induction types, the switch element may be used in a high-voltage circuit, but the induction element requires the insulating transformers or transformer windings. The choice between the switch and the combination type of regulator depends again upon the requirements. On long single lines, or even on long multiple interconnections, it would seem that the switch type should be satisfactory because of the high resistance and reactance of such lines, but for short lines or a combination of short and long lines, a more uniform voltage change may be required. In case the regulators are operated by hand or motor, a finer adjustment can be obtained by the combination type, but in case this type is operated automatically, about as close a regulation as can be obtained is one per cent either way from normal; that is, the combination type of regulator corresponds to the switch type having one per cent steps, and on this basis the deciding factor is probably the price.

The switch or step type is certainly the simpler in construction and has a higher efficiency and should therefore be used wherever conditions warrant.

Mention was made of the desirability of in-phase and out-of-phase control for parallel connecting lines. The results obtainable by the use of two polyphase induction regulators were fully illustrated and described in the London *Electrician* of Nov. 6, 1914, but the system has not been generally adopted by operating companies because of the cost and the difficulty of making this arrangement automatic. However, as the multiplying of lines increases and the necessity of controlling both the wattless and the power current in such lines is recognized, this arrangement will undoubtedly be more generally used.

**F. F. Brand:** Mr. Hill has outlined very well in his paper the different methods in use for changing transformer taps under load, and he has brought out the difference between the two principal schemes—the one of using parallel circuits, and the other of using the preventive reactance or auto-transformer.

I am inclined to take issue with him on the application of two different schemes, as I would consider that the scheme of using the preventive auto-transformer to derive mid-voltage between taps is more applicable to small transformers, and the other scheme of using parallel circuits is better adapted to large transformers.

For a 20,000-kv-a. transformer with taps 5 per cent apart, and with a preventive reactance used to derive the mid-point, the nominal size of the reactor is approximately 1000 kv-a., and the losses in the reactor would be of the order of 10 to 20 kilowatts. Furthermore, on this scheme in those positions in which the preventive auto-transformer is used to derive the mid-voltage, there exists a circulating current which is constant irrespective of load conditions, and the losses in the reactor and that portion of the winding through which the circulating current flows must be considered a part of the light-load transformer loss.

Also the use of the preventive auto-transformer to derive the mid-point does not give equal voltage steps, and a difference in the voltage derived from the true mid-point is greater the lower the power factor. For instance, at 80 per cent power factor and full load, the voltage actually derived is of the order of 1¾ per cent from one tap and 3¼ per cent from the other tap instead of 2½ per cent from each.

Better conditions of obtaining the true voltage required are obtained if the circulating current is increased, but this obviously increases the losses in the tap portion of the transformer, the size of the tap portion, and the size and losses of the auto-transformer.

It is quite true that the preventive auto-transformer scheme enables a slightly simpler winding to be used than parallel circuits, although it should be understood that it is not necessary in the parallel-circuit scheme to provide two complete parallel paths throughout the total winding. It is necessary to parallel only a portion of the winding to obtain sufficient reactance between these portions to limit the circulating current to a reasonable value in the transfer position. In fact, modern practise is to use a single-circuit winding including the tap portion and a parallel-circuit portion sufficient to obtain necessary reactance between these parallel portions. There are, therefore, only nine taps on a winding designed to give nine voltages, each tap being carried through two ratio adjusters respectively connected in circuit with the parallel portions.

When it is considered that in order to obtain the necessary reactance control, paralleling portions of the winding is undesirable, the preventive reactance, or auto-transformer, connected externally to the transformer winding, may be used. Ratio adjusters are used to select the taps, and the normal operating position is with both ratio adjusters on one tap. The current then divides in the halves of the preventive reactance, and the ampere-turns neutralize one another; therefore, the voltage drop is practically negligible. This scheme cuts the size of the preventive reactor to half that of when the reactor is used to derive the mid-voltage between taps. The losses are therefore less, and circulating current exists only at the time of transfer.

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The question of whether or not it is desirable to reduce the number of operations depends principally upon the reliability of the apparatus to accomplish the tap changing. To my mind, the elimination of circulating-current losses at periods of light load, and the fact that one obtains an exactly equal division in voltages by the plan when the normal operating position is always at both ratio adjusters on one tap, far outweighs the slightly more complicated operating mechanism.

Referring to Mr. Blume's paper—it seems to me there is a good opportunity for the combination of load-ratio control transformers and synchronous condensers on transmission-line work. As he has pointed out, there are certain advantages in each type of control. The synchronous condenser has the advantage of controlling power factor, and therefore the possibility of reducing the losses. If used in combination with variable-ratio transformers, it is quite possible to reduce the losses under certain operating conditions; for instance, on the light-load condition, a synchronous condenser, if used to control the voltage draws lagging current, increases the line current and line losses, and the losses in the condenser of course increase as the current increases. When using a variable-ratio transformer, it should be quite possible to do away with lagging requirements of a condenser, except, perhaps, when it is necessary to hold down voltage on a long, lightly loaded, high-voltage line, when the voltage increases due to capacity charging current.

With a variable-ratio transformer it is possible to reduce leading kv-a. requirements of the condenser. That is, in the case of lines of very poor regulation it is not necessary to raise the power factor to unity or to leading in order to maintain proper voltage regulation. The combination of these two, that is condenser and variable-ratio transformer, may easily result in both cheaper equipment and very much lower losses over the average operating conditions.

**H. O. Stephens:** At first thought, one would be inclined to question why so many different methods of changing transformer voltage under load are used and if it would not be better and more economical in the long run to standardize upon one method? This is a perfectly logical question, but the very nature of the object to be accomplished makes it very difficult to standardize upon one scheme that would be universally applicable. The variations in voltage and current are so great that one type of circuit-interrupting device can hardly be used throughout the range and if the voltage as well as the current to be interrupted is high, it is desirable to keep the number of circuit-interrupting devices as small as possible for the sake of economy and size.

Additional complications, such as auto-transformer connections, tertiary windings, etc., that may be introduced into the transformer, demand that the designer be given considerable latitude in his choice of equipment. However, it is very desirable to standardize upon as few methods as possible and considerable help in this direction can be given by the users of the apparatus by slightly modifying their requirements to meet the exigencies of design.

There is a tendency among certain operators to demand extremely small voltage steps on transformers equipped with load-ratio control which I believe, in most cases, is not justified. Even when automatic operation is specified, taps in steps less than 2½ per cent can hardly be considered necessary. It should be remembered that with 2½ per cent taps, the voltage can be adjusted to within 1¼ per cent of the desired value.

An induction regulator, which is generally considered to be a very satisfactory voltage-regulating device, requires at least a plus or minus variation of 1 per cent from the desired voltage for the contact-making voltmeters to function, and usually this difference is 1½ to 2 per cent, so that the transformer with 2½ per cent taps can be operated to give virtually as good regulation of voltage as an induction regulator. For this reason I believe the extreme refinement supposedly accomplished by the use of the so-called "step induction regulator" with a transformer with taps is an unnecessary refinement. When desired, a very small percentage in tap variation can readily be accomplished by the multiple winding scheme of transformer operation.

**W. M. Dann:** I think Mr. Stephens has hit the nail very squarely on the head when he talks about standardization of tap-changing-under-load equipment. Of course, this field of tap-changing under load is really in its infancy in spite of the pioneer equipments that have been in use for several years. The trend in the design has been very much toward simplification and standardization. I am very much in sympathy with Mr. Stephens' remarks about the demands of the industry itself. If we can get the operators to simplify some of those demands and make use of equipment that has already been designed and installed, it will help very materially towards that ideal of standardization.

**K. A. Oplinger:** It is unfortunate that no standard terminology exists upon the general subject of changing taps on transformers under load. Equipment for this purpose is usually called a tap changer but at other times the term "ratio adjustor" is used. The N. E. L. A. has started to collect data on equipment for controlling the voltage ratio of transformers under load and already a number of reports have been published covering these data. Although this equipment has developed very rapidly during the past two years, it is now fairly well standardized and a uniform terminology would be very desirable.

For example, the single-winding method, as described in the reports mentioned above, now appears in Mr. Palme's paper under the title of "multiple-switch method." This method has also been called the "preventive-auto-transformer method" because a preventive auto-transformer or protective reactance is switched along the transformer taps. This method was one of the first employed to change transformer taps under load.

The term "single-winding method" appears to be most appropriate for this particular scheme as it is comparable with the term "double-circuit method" which requires double windings on the transformer.

In Mr. Palme's comparison of the single-phase tap changer and the separate three-phase regulating transformer there are several additional items which might be added to this comparison. The over-all efficiency of the transformer bank will be lowered by the separate regulating unit, due to the additional losses in both the exciting and the series transformers. Furthermore, if a separate regulating unit is used, provision must be made of the additional leads required between the transformers and the regulating unit. Although it is pointed out that the separate regulating unit isolates the switches and permits operation of the power unit without the regulating unit, these features may also be obtained if single-phase tap changers are used with all switches external to the transformer tank.

With reference to the automatic control of tap changers, an interesting application is under consideration at the present time in which the tap changer will automatically control the flow of wattless kv-a. between two generating stations in inverse proportion to the load on the two stations. A transformer with equipment for changing taps under load is to be used as a tie-in between the two stations and as the load on one station is increased the tap changer will automatically operate to transfer the wattless kv-a. to the other station. This same control might also be arranged to regulate the wattless kv-a. in direct proportion to the load of the two stations.

Other methods of automatic control may be arranged to have the tap changer limit the exchange of wattless kv-a. between stations or to have the tap changer responsive to changes in power factor.

**J. S. Lennox:** Mr. Hill brought out one point that I think is a very good one, and that is that with the parallel-winding method, the transformer must be protected against an accidental stoppage of the mechanism leaving a load on one-half of the winding. It is for that reason, I think, that the parallel-circuit method has developed into what Mr. Hill calls a single-winding method, but distinguished from the arrangement that Mr. Hill

has described in his paper by the fact that the circuits are broken in a separate device from the one that changes the tap connections, and by so doing, it is possible to place inside the transformer adjacent to the windings, a tap device of such simple and sturdy design that it involves no maintenance problem, and permits the use of small steps. Therefore, there is low deterioration of the contacts in the contact-making device placed outside the transformer tank and easily accessible for renewal of contacts.

**L. H. Hill:** Mr. Brand made a comparison of the two methods employed, the single-winding method and parallel-winding method, and he mentioned the increase in loss by the use of the preventive auto-transformer. It is obviously true, that additional loss will be introduced by the introduction of additional apparatus. However, with the parallel-winding method, additional loss is also introduced in a more indirect manner. Reactance is required to effect the tap change regardless of the method used, so that if the parallel-winding method is used the windings must be so arranged and so interlaced that sufficient reactance will be obtained between them to limit the current to a reasonable value during the transition period. That ordinarily means making the core of the main transformer larger and naturally introduces additional loss, although as a general thing it is true that it is not as large as would be obtained by means of the preventive auto-transformer.

He also mentioned that in the single-winding method using the simplified preventive auto-transformer, unequal steps were obtained. Naturally, when the equipment is operating with one-half of the preventive auto-transformer in series with the line, it acts as a small series reactor. Since the drop is almost entirely reactive it is subtracted from the theoretical tap voltage at right angles, which at the higher power factors does not cause any appreciable unequality in tap voltages. The difference in reactance obtained on the two different operating positions of the preventive auto-transformer must be taken into account, however, under certain conditions of paralleling.

For example, assume a transformer with four per cent impedance, and with a two-one-half per cent tap, or five per cent in voltage across the whole winding of the preventive auto-transformer. The impedance volts at full load through one-half the auto-transformer in series with the line would be about one per cent or an increase in reactance from four to five per cent on alternate taps, which would not give good paralleling conditions with a transformer which did not use the preventive auto-transformer. However, with a transformer with eight per cent impedance, the change from eight to nine per cent impedance would be proportionally less, and can be compensated for by making the impedance of the main transformer winding midway between the two values, giving good paralleling conditions.

In cases where very close paralleling is required or even assuming conditions where the transformers are to be operated at very low power factor, when the impedance drops and unequality of steps might be of some importance, it becomes a simple matter to use the short-circuiting switch shown in Fig. 3 of my paper. In that case, the series impedance drop is eliminated entirely.

These things are merely a matter of detail design, and we feel the same as Mr. Lennox, that the two methods, single- or parallel-winding, could be changed from one to the other at will. The point is that the method using a preventive auto-transformer is fundamentally a single-winding method as distinguished from a parallel-winding method. A number of variations of the single-winding method are possible. For conditions of ordinary design, the range in taps to be obtained is generally not more than 20 or possibly 25 per cent in steps which ordinarily would not require more than 6 circuit breakers.

If it is desired to cover a very wide range, for example, 100 per cent range by this method, it is true it would not be desirable to add 5 or 6 more switches, as it would make a large and expensive mechanism. In this case, the switches in each tap lead may be contactors or some sort of ratio adjustors with auxiliary circuit breakers in the two end connections to the preventive auto-transformer to open and close the circuits. Even with this type of equipment the few taps required by the single-winding method make it possible to place all switches outside of the main tank, so that all moving parts are external to the main case.

In all the equipment which we have built with the exception of the early installation using the parallel-winding method, all switches were outside of the tank, and our policy in now building the single-winding method exclusively is based on experience with both types. We have built these 20,000-kv-a. single-phase units, which are large units, with the parallel-winding method, and we have built units up to 25,000 kv-a. with a single-winding method, and we are now building some 33,000 kv-a. single-phase units using the single-winding method.

A comparison of the parallel-winding method and single-winding method when used to obtain a typical range of eight, two one-half per cent taps may be of interest.

With the single-winding method five taps and five switches are required. With the parallel-winding method, nine taps are required in each winding or a total of 18, making almost four times as many taps and switches.

The measure of the inherent reliability of equipment for a certain performance is based on the amount of apparatus and moving parts required and the amount of operations of that equipment, and the amount of circuit interruptions of that equipment are a measure of the maintenance required and performance to be expected over a long period of time. To change taps by means of the parallel-winding method there are required at least six switch operations, whereas but one is required with the single-winding method, or in case the short-circuiting switch is used, there are but two.

In the case of the parallel-winding method there are two circuit interruptions per tap change. In the case of the single-winding method a circuit is closed instead of opened on every alternate tap change giving the equivalent of one-half a circuit interruption per tap change over the whole range.

With the parallel-winding method, it is not commercially practical to build each of the windings capable of carrying the whole load current continuously. Each winding is overloaded during the tap-changing operation and a protective system is needed to protect the windings in case of accidental stoppage of the equipment during a tap-changing operation. With the single-winding method no winding is overloaded during the tap-changing operation.

The few taps and switches needed with the single-winding method permit mounting all moving parts outside of the main tank, which is desirable from the standpoints of maintenance, operation and safety.

The equipment developed for use with the single-winding method is very simple. Proper sequence of all switch operations is assured by positive mechanical drive using simple gears and linkages.

In the parallel-winding method, there is a great amount of mechanism needed inside the tank which must be connected to the operating mechanism outside, in order to assure proper sequence of operations between the internal switches and the external circuit breakers.

The statement has been made that the parallel-winding method is more applicable to large units. I have already mentioned some of the large units which have been built using the single-winding method. We recently built some three-winding units rated at 20,000 kv-a. water-cooled (25,000 kv-a. forced-cooled), single-phase on each winding. They were arranged to change taps under load on two windings, one 66-kv. and the other 132-kv. solidly grounded. To change taps with the single-winding method, five switches are used in the grounded end of each winding. The transformer has but few taps in it, a single winding, (no complicated interlacing of paralleled sections) and the two preventive auto-transformers are mounted at each end of the core, making a very simple arrangement for handling

one of the largest and most complicated cases of tap changing under load likely to be encountered.

With the parallel-winding method a very complicated transformer with a great number of taps would result which would be very difficult to bring out. It would be necessary to interlace two 132,000-volt windings and two 66,000-volt windings, giving the equivalent of a 5-winding transformer, which is a simple 3-winding transformer when the single-winding method is used.

The separate regulating unit has been proposed as being desirable for such cases and that is undoubtedly true if the parallel-winding method is used, because it is very undesirable, in fact impracticable, to build such a transformer with the parallel-winding method while it is entirely practicable and simple to do it with the single-winding method. The single-winding method can be applied to any size and rating of transformer by the use of the series transformer for very high-voltage applications.

The separate regulating unit has certain definite fields of application, for example, where it is desired to use the voltage-control equipment on different parts of the system, or where the main units are already installed and additional control is desired. However, in the ordinary installation of single-phase units the tap changers can be put on each of these units including the spare, giving a very simple, reliable and efficient form of installation.

It is true that when the spare transformer is used there are four separate mechanisms to operate with each bank. If a separate three-phase regulating transformer is used, as was mentioned, it is necessary to install underground or overhead structures to connect to the main units which, of course, increases the installation costs and space required and introduces far more losses than the preventive auto-transformer introduces with the single-winding method on the main transformers. The separate regulating unit generally has two cores, an exciting transformer and a series transformer, which obviously are much larger than in the auto-transformer used with the single-winding method, and naturally introduce a very considerable operating loss.

The regulating unit has the advantage that it does keep all the moving parts outside of the main transformer case, which is very desirable. But, the same thing is done with the single-winding method on the main units. The three-phase regulating unit has the additional drawback, that no spare tap-changing equipment is available as is the case when four single-phase transformers or seven single-phase units are used. Spare tap-changing equipment is becoming almost as important as spare capacity for the transformer.

There is one other place where the separate regulating unit might be desirable. In case the three-winding unit first mentioned had been arranged with an ungrounded neutral, so that it would be necessary to use the series transformer, in order to keep the tap-changer voltage down to a low value, then it would require two series transformers, in each winding. The series transformers are ordinarily placed inside the tank, along with the preventive auto-transformer and that would make quite a large number of transformers all in one tank. In the case of such a very special application it might be desirable to use a separate regulating unit, but even then, the single-phase regulating unit for the reasons just mentioned, has some advantage over the three-phase unit. Single-phase units of that type are now being built.

Mr. Stephens mentioned that on account of the steps required, it seems hardly necessary to use the step induction-regulator equipment. That is true perhaps in many cases from that point of view, although on account of the fact that no circuit interruptions are required for a tap change it is very good from a maintenance point of view, since it may be operated very frequently without any deterioration on the contacts or oil as would be the case with any step type of equipment, for this reason it is well suited for electric furnace operations such as Mr. Palme mentioned, or in synchronous-converter or certain automatic-substation applications.

**L. F. Blume:** In the paper by Mr. Hill, mention is made of the use of a preventive auto-transformer bridging across adjacent transformer taps. This auto-transformer is described as being physically of a relatively small size, but designed to operate at high-flux density. Operating with one contactor open, with the entire load current flowing in one winding of the auto-transformer, the saturation of the iron in the reactor prevents excessive voltage drop.

I am inclined to believe that this method of operation is open to the objection that the saturation of the iron in apparatus connected in series with a circuit introduces serious wave distortion in the line voltage.

Before coming to the conclusion that the arrangement having the fewer number of taps is to be preferred to the one using a greater number, consideration must be given to a number of advantages which are obtainable by the use of more taps. First, by increasing the number of taps, it becomes possible to reduce the voltage short-circuited and also makes it possible to avoid having a circulating current in an operating position, both of which materially add to the electrical efficiency.

Second, increasing the number of taps reduces the energy which must be ruptured, and on this account both the wear on contacts and the deterioration of oil are effectively reduced. The result of this is that contacts and oil must be changed less often when more taps are employed.

Although these arguments are negligible when ratio control is used for relatively small kv-a., in the larger equipment they become very appreciable and cannot be ignored.

**P. H. Thomas:** The tap-changing transformer is in many ways a substitute for the synchronous condenser. It is a simple, cheap and effective method of accomplishing the same results under certain conditions. The great value of our synchronous type of apparatus, however, is its automatic quality. We can set it in a system with the proper regulators and then changes that have to be made due to changes in load and accidental conditions will occur automatically. In the most modern apparatus or in apparatus which is to be built hereafter, they occur sufficiently quickly to prevent synchronous apparatus dropping out of step.

This is an entirely different thing from adjusting conditions by hand to reduce power factor or to get a satisfactory voltage for customer circuits.

To have the tap-changing outfit the equivalent of the synchronous condenser for this sort of work, it is necessary that it be able to operate quickly enough to produce the necessary changes before the loss of synchronism and other things which we fear when sudden load conditions occur. That is one of the sides of the question that must be studied very carefully, the speed of action and the automatic control of the tap changes. It may be in response to voltage; it may be in response to power transmitted over some circuit; it may be in response to power factor; it may take account of positive and negative power factor; it may be dependent upon circuit-breaker operations, or many other conditions,—according to the particular place in which the tap changing is to be used.

Take, for example, a tie line between two large systems which must pass current backward and forward, according to the variations of load, perhaps at different times of the day. That is an exceedingly exacting duty on a transmission line and transformers and calls either for a wide change of power factor if the voltage is to be maintained constant at the two ends with a change in direction of the load, or a change of tap ratios.

If the large systems are to operate successfully in parallel, relying on the use of tap changers to control the interchange of power backward and forward, without disturbing voltages, they must act very rapidly, and they must act under the control of the necessary factor to produce such a result.

I don't know just how successful the present apparatus will be in that sort of thing, and I wonder if some of the authors could give us a little information as to what extent the tap-changing operations can be counted upon to meet accidental and automatically controlled changes in load.

**L. H. Hill:** Many types of automatic control to meet more or less steady-state conditions have been developed. The only installations in service that I know of are responsive only to voltage changes. The six 12,000-kv-a. units, illustrated in Fig. 6 of my paper, are operating under automatic control and maintain the bus pressure approximately constant. Under automatic control the tap-changing equipment is of course subjected to considerably more severe duty than would be met with under ordinary manual control. Under manual control, the tap-changing equipments in operation generally average not more than five operations a day, whereas under automatic control they may operate ten times as many.

To eliminate unnecessary operations and avoid hunting it is desirable to insert some time delay, the length depending on the application.

It is also perfectly feasible to work out automatic control to transfer the power at a constant power factor.

Mr. Oplinger mentioned a case where the tap changer will automatically control the flow of wattless kv-a. between two generating stations in inverse proportion to the load on the two stations. There are almost an infinite number of arrangements that can be used for automatic control under these more or less steady-state conditions. However, for the purpose of using tap-changing equipment to effect the stability of a system under transient conditions, the present equipment is hardly adequate, because the ordinary tap-changing operation requires a matter of seconds. With our equipment, it requires about four sec. to change one tap. It would be entirely practicable to increase this speed perhaps to one sec., which would even then be hardly short enough to do much good under transient conditions.

Mr. Blume in his later discussion mentioned that when the auto-transformer is connected in series with the line it might give trouble, due to harmonics. I think Mr. Blume is confusing some of the earlier auto-transformers which we used and which were provided with the short-circuiting switch. When the short-circuiting switch is used the auto-transformer can be used working high on a saturation curve, so that it saturates under double-load conditions but in that case it is short-circuited when in series with the line, so there is no voltage available to put harmonics on the line.

When the auto-transformer is used in this manner without a short-circuit switch, then as mentioned on the third page of my paper, the auto-transformer is provided with air-gaps in its core, so that the core does not saturate and a straight-line characteristic is obtained.

**L. F. Blume:** I wonder whether Mr. Thomas in his discussion did not have in mind more particularly the longer high-voltage lines. As far as I know, the use of tap-changing equipments has been applied for the most part to the shorter lines, by which stations not so very far apart are interconnected; where the power to be transmitted is large, and where the reactance between stations is not great, as it is in very long-distance transmission lines.

In long-distance transmission, the effect of capacitance and of line reactance introduces problems which were not considered in the paper. It was assumed that line capacitance could be neglected, and that the amount of line reactance was insufficient to introduce the question of stability.

In the longer lines, where the reactance is high, the paper shows that the higher reactance means that the kv-a. required for a synchronous condenser to maintain constant voltage is proportionally smaller than ratio-control equipments. For example, comparing a low-reactance line with a high-reactance line, the size of the synchronous condenser required to maintain constant voltage with increasing reactance does not increase in kv-a., but the size of the ratio-control apparatus is directly proportional to the reactance.

So, for the longer lines, ratio-control apparatus is not only relatively more costly, but also on account of other considerations, such as stability, is probably unsuitable.

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# Discussion at Summer Convention

## ELECTRICAL REPRODUCTION FROM PHONOGRAPH RECORDS[1]

(Kellogg)

Detroit, Mich., June 23, 1927

**C R. Hanna:** In the paper by Mr. Kellogg no mention has been made of factors which determine the sensitivity of the pickup device other than that mass has something to do with it.

This statement is made: "The foregoing comparison of magnetic systems does not take into account the possible power output of the winding, nor is the elastic stiffness required to hold the armature in its mean position allowed to weigh in the choice. The comparison is wholly from the standpoint of obtaining the maximum open-circuit voltage with the minimum effective inertia of moving parts."

This discussion has to do with the factors which affect the sensitivity. The first of these is elastic stiffness which is not taken into account in the paper. In Fig. 8 of the paper, the curve given for the reaction force on the record against frequency, shows that the pickup device requires greater driving force in the low range of frequencies for a given velocity, and therefore, may cause excessive wear on the record. The stiffer the restoring member the steeper this curve will be. The stiffness of the restoring member, which in the design described by Mr. Kellogg is principally in the upper two rubber plugs, must be sufficiently great to prevent the armature from being pulled over to one pole or the other. The presence of the magnetic poles thus produces an effect which is known as magnetic reduction of stiffness and this reduction of stiffness must never be greater than the mechanical stiffness of the mechanical restoring member. In manufacture, it is never possible for the magnetic reduction of stiffness to be greater than some 50 per cent of the mechanical stiffness, leaving about 50 per cent as net stiffness. To prevent excessive wear to the record the net stiffness must be small, and since the magnetic reduction of stiffness bears a constant ratio to the mechanical stiffness, the magnetic stiffness cannot be greater than a certain amount. This necessitates either a weak magnet, a long air-gap, or fairly small pole faces, all of which make for low senstivity.

The other factor that weighs in sensitivity is the inductance. If more turns are wound on the coil, or a higher-ratio step-up transformer is used, to get greater output voltage, the inductive impedance of the device may become too high for the circuit into which it is to operate; namely, the grid of the vacuum-tube amplifier. Thus, the effective inductance of the device has a definite upper limit.

Now, as a general proposition, it can be shown that if magnetic saturation and leakage are negligible, the sensitivity expressed in volts per unit velocity at the needle is dependent upon two factors only: (1) the magnetic reduction of stiffness, which is limited because of wear on the record at low frequencies; and (2) the inductance of the device, which is limited because of the impedance of the vacuum tube into which the device is to operate.

1. A. I. E. E. Journal, October, p. 1041.

The relation[2] is Volts/(cm./sec.) $= \sqrt{10^{-7} \times \text{Inductance} \times \text{Magnetic Stiffness}}$. When these two factors are held constant, all of the arrangements which were shown in the paper will have the same sensitivity characteristic, provided magnetic saturation or magnetic leakage do not come into play.

And so the advantage of one construction over another, magnetically, in any case will be due to less leakage or less saturation, or both. Of the various arrangements having low saturation and leakage, the above relation shows that the one which is most suitable for mechanical considerations may be chosen without sacrifice of sensitivity.

**E. W. Kellogg:** Mr. Hanna has called attention to the fact that in making my choice from the numerous possible magnetic arrangements, I have limited my consideration to certain criteria; namely, securing the maximum volts per turn for a given magnitude of stored energy in the inertia of the vibrating armature. He introduces a different point of view, in which the stiffness of the armature mounting is to be limited in order not to cause excessive wear on the record, and he reaches the interesting conclusion that if well designed, almost any of the magnetic systems is as good as any other. This conclusion is itself a vindication of the point of view adopted in the paper. With armature stiffness as the controlling factor, there is no choice; but when we take small inertia as the desideratum, the choice is narrowed down to one or two arrangements. The reduction of inertia of the vibrating parts is desirable from the standpoint of wear on records, but is especially important for high-quality reproduction. The lighter the moving parts, the higher will be the frequency at which whip resonance occurs, and therefore the greater the range of frequencies which can be reproduced. The fact that the force on the needle tip is greater at low frequency where stiffness is the controlling factor than at high frequency where inertia predominates may be taken as an indication that the effort to keep the inertia low was successful. The stiffness is not materially greater than that of mechanical reproducing systems, and if experience shows that greater flexibility is important, it will have to be secured, as Mr. Hanna's analysis shows, at the cost of lower sensitivity. In this connection I should like to commend Mr. Hanna's I. R. E. paper, for it is instructive and interesting. But the case considered there is a loud-speaker design and the factor which is of primary importance in one problem is not necessarily so in the other. The fundamental difference is that in the loud-speaker drive the current supplied results in a certain force being applied to the diaphragm and the amplitude is determined by the ease of movement of the diaphragm, while in the phonograph reproducer, the amplitude is practically fixed by the groove in the record.

The question might be raised why voltage per turn instead of power output was taken as the measure of efficiency of the magnetic arrangement. When the reproducer was first designed, it was expected that it would be connected directly to the grid of a tube, without a transformer. In this case, the minimum size of wire and available winding space being practically fixed, the useful output would be measured in terms of the voltage per turn developed by a given needle velocity. If the reproducer is used with a transformer, the possible power or volt-ampere output appears to be a more logical basis for comparison of different structures. I should like to add a brief discussion of this case.

If the transformer has a step-up ratio $N$, and if the capacity to ground of the tube grid and wiring is $C$, the effect of the transformer is to load the reproducer winding with an effective capacity $N^2\ C$. But this must not resonate with the winding inductance within the working range of frequencies, for such resonance would impair quality of reproduction. The lower the winding inductance the greater the step-up ratio which may be employed. Hence, if we can lower the inductance by raising the reluctance of the magnetic circuit without reducing the flux change which results through the winding from a given needle movement, we make it possible to use a higher step-up ratio and apply more voltage to the grid. A consideration of the several magnetic systems illustrated in my Fig. 4 will show that we have no reason for revising our choice of double-acting or push-pull systems in preference to single-acting systems, or of rocking rather than translation type armatures.

There is, however, a different aspect to the comparison of the half-rocker and full-rocker armatures. It was argued in the paper that if the reluctance of the magnetic joints at the pivot of the half-rocker is kept low, the voltage developed would be nearly as much as with a full-rocker. For simplicity, let us take the ideal case in which this pivot joint reluctance is zero. The voltage per turn will be the same as with a full-rocker, while the inductance would be twice that of the full-rocker device. This would necessitate reducing the transformer step-up in the ratio $1/\sqrt{2}$ or 0.707, and the voltage at the grid would be reduced in the same ratio, which corresponds to cutting the power in half.

Were it not for practical difficulties having to do with clamping the needle, the full-rocker armature would perhaps have been chosen. But these difficulties were serious, and the advantage of the full-rocker is not so great as the two-to-one power ratio would make it appear. In the first place, this power ratio is based upon the assumption that both ends of the full-rocker move as much as the one moving end of the half-rocker. This would mean more metal to be moved, and if the whip frequency is to be kept high, there would have to be a compensating reduction in amplitude. Again the full-rocker, if proportioned to give twice the power output of the half-rocker, would require twice as stiff a mounting to stabilize the armature in the air-gaps, and this, as Mr. Hanna has pointed out, is objectionable from the standpoint of record wear. By the time these factors are compensated by changing the ratio of armature to needle movement, practically all the advantage of the full-rocker armature has disappeared.

## HIGH-VOLTAGE MULTIPLE-CONDUCTOR JOINTS[1]

(Peterson)

Detroit, Mich., June 23, 1927

**D. W. Roper:** I am not going to subscribe to the implications in the paper that this type of construction is the only one that will result in successful high-voltage joints, but I can subscribe to the statement that single-conductor cable joints which are made up in essentially the same manner as the joints on each of the three conductors in Mr. Peterson's three-conductor joints, are very successful. In Chicago we have about 750 single-conductor joints made up very much the same as the individual conductors in Mr. Peterson's metal-sheathed cable joint; that is, they have the reinforcement of the insulation, the extension of the metal sheath to the point of maximum reinforcement and then a tapering of the reinforcement as well as a tapering of the conductor insulation.

Mr. Peterson mentions the careful selection of materials, absolute cleanliness and careful workmanship. In order to secure the latter two features in the single-conductor joints which we made, we started a school for the training of our cable splicers, using for the purpose a full-sized cable. We had each one go through all of the details process of making up a joint, or several joints if necessary, until he became proficient in the mechanical execution of the several processes.

To make sure that a man was proficient, after he had made

2. C. R. Hanna, Design of Telephone Receivers for Loud-Speaking Purposes, *Proceedings*, I. R. E., August 1925. The relation given in this paper is for the force factor and must be divided by $10^7$ to obtain generated voltage per unit velocity. While the proof of the relation is given for a particular structure, it can be shown that it applies to all devices in which the inductance varies inversely with a linear function of the displacement of the moving iron member.

1. A. I. E. E. Journal, June 1927, p. 559.

up each joint, it was cut apart, and examined, and the imperfections in his workmanship were pointed out to him. He was required to repeat the process as often as was necessary,—generally only two or three times—until he had eliminated those imperfections in his workmanship. After that was done, we had him make up a joint at a different location where a high-voltage test transformer was available, and in order to secure economy, we had three joints made up in series putting high-voltage potheads on the ends of the cable and applying the high-voltage test required by the specifications to be applied to the cable. In each case, the failures occurred in the cable and not in the joints.

Since then, we have made up 750 joints on the 66-kv. cable and placed them in service, and have applied the usual high-voltage test to the completed lines before placing them in service. There have been no failures whatever on any of the joints, either during the construction training, or on the testing of them after the completion of the lines or in service. We have had a total of about 400 joint-years of service on this type of joint. So I think, as Mr. Peterson said, we are rapidly approaching the condition where joints are stronger than the cable.

**E. D. Eby:** In this problem of splicing high-tension cables, it is gratifying to note in Mr. Peterson's work an honest attempt to make use of scientific principles of design.

His adoption of the tapered reinforcement of conductor insulation adjacent to the lead sheath with the reinforcement overlaid with metal tape unquestionably constitutes one of the main factors in the success of his design. I advocated this construction to the Cleveland Electric Illuminating Company in 1923, when the 66,000-volt single-conductor cable system was first being developed. I think this was the first occasion on which this construction was proposed and described. How effective it has proved in the solution of cable-joint problems is evidenced by the fact that practically all of the higher-voltage joints have been made in this way and with a success which has been unparalleled.

A feature of which Mr. Peterson has not taken advantage, but which has worked out to complete satisfaction in General Electric designs, is that of stepped conductor insulation adjacent to the connector. Mr. Peterson found trouble with both stepped and penciled insulation in some of his designs but this was probably due to the use of inflexible paper tape. With a flexible tape such a bias-cut varnished cambric, there is a much better bond between the conductor insulation and the hand-wrapped insulation. The stepped surface, however, offers decided advantage over the penciled surface. An exact number of tapes can be removed at each step so that the remaining insulation is of a known and uniform thickness. Accidental cutting into the remaining insulation, as sometimes happens with a penciled surface, is thus wholly eliminated. The tearing of the tapes against a fine steel wire looped around the conductor leaves a spongy edge which fills well with the flushing compound and forms an elastic cushion under the hand applied tape. The uniformity of the remaining insulation is particularly evident in the case of sector-shaped conductors where uniform penciling becomes even more difficult than with round conductors.

While, as Mr. Peterson remarks, it is true that the hand-wrapping of joints with tape has always been a long and tedious operation, it is also true that with the more scientific designs now available, the amount of taping to be done has been so much reduced and the kind of tape to be applied so much improved that hand-taped joints are not only wholly practicable from the installation standpoint, but are proving entirely reliable in service. Even machine wrapping of the tape does not offer sufficient advantage to warrant the use of machines except for paper tape. Furthermore, the introduction of the specially processed varnished-cambric tape with low dielectric losses has removed the one advantage of paper tape which formerly existed so that now a hand-taped varnished-cambric joint stands second to none, both with regard to ease of installation and its reliability.

While barrier tubes in three-conductor joints have proved disappointing in some designs, they are not an objectionable feature when properly shaped and located with respect to the conductors. The writer has developed a design for 33-kv. sector cable in which the barriers consist of sections cut lengthwise from standard Kerkolite cylinders, two such sections surrounding each conductor within an outer cylinder and holding it rigidly in definite relation to the other conductors and to the outer casing. The construction prevents displacement of the conductors within the casing which might occur either from short-circuit stresses or from mechanical movement of the cable.

In Mr. Peterson's joint for belted cable, he has found it desirable to enclose each conductor with an individual reinforcement of tape where it emerges from the belt. With no barriers to support the cables at the center of the joint, this serves a good purpose, mechanically. Electrically, however, it is not necessary, since a reinforcement enclosing all three conductors and overlaid with metal tape will accomplish the desired results. Sample joints tested by the writer have shown no weaknesses in the crotch.

Three-conductor cable of the belted type for 20,000 volts and above will probably give place sooner or later to cable of the shielded type so that future interest in joint design for three-conductor cables will center largely in the latter. It is natural that with each separate conductor enclosed in a metal tape under the lead sheath, a similar construction should prevail at the joint. Apparently Mr. Peterson did not have much success with such joints in which the tape was carried all the way across the hand-wrapped insulation. Here again perhaps the difficulty was with the kind of tape and a penciled rather than a stepped surface. At any rate, the writer has had no difficulty in making a satisfactory joint of this kind. Such a design for 33-kv. shielded cable

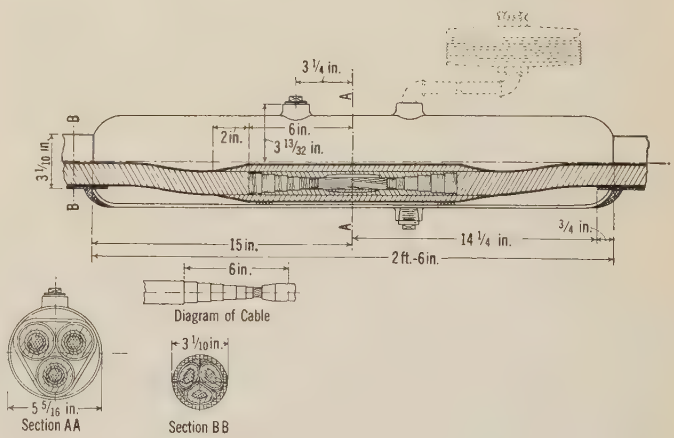


Fig. 1—33-Kv. 3-Conductor Joint for Shielded Cable

is shown in the accompanying Fig. 1. The simplicity of this joint is at once apparent. The fact that each conductor is wholly enclosed within the grounded metal tape eliminates the transition made in Mr. Peterson's design from the equivalent of three single-conductor cables under the lead sheath to the equivalent of a three-conductor unshielded cable in the center of the joint.

That the totally shielded form of joint for three-conductor shielded cables is entirely practicable is further evidenced by the complete success of a 66,000-volt single-conductor joint of equivalent design. A further advantage in a totally shielded joint is the absence of immediate danger which results from an incomplete filling of the joint casing with oil or compound. In the open construction with oil between the conductors under stress, the absence of oil would be expected to develop trouble rapidly. In the totally shielded construction, providing moisture was

excluded, an incomplete filling of the casing would not be serious.

Such descriptive papers as this will do more than anything else toward harmonizing ideas and unifying practise. There are certain fundamental principles in the design, installation and operation of cable joints which this publicity will gradually help to establish. The standardization of materials and methods in this class of work is just as desirable as in other classes of equipment.

**D. M. Simons:** I should like to make a few remarks, particularly on the joints for Type-H or metal-sheathed cable. We have been making Type-H cable since 1914 (in commercial quantities since 1919), and have given the matter considerable thought. I approve of Mr. Peterson's solution, but I should like to point out that there is another solution.

I believe everyone agrees that one of the great advantages of Type-H cable is that all the so-called "crotch" failures can be avoided, since the metal can be carried into the joint until there is sufficient separation between the insulated conductors to avoid trouble. Apparently, however, there are two schools of thought on Type-H joints, differing in whether or not the metal foil should be carried completely across the joint or not.

We have made both kinds of joint, ourselves, having made those similar to the kind Mr. Peterson has described, with one refinement in addition; namely we used a large lead wire at the edge of the metal in order to reduce somewhat further the stresses there. The other form, which we have generally preferred, is to carry the metal shields across the joint. If this is done, then, theoretically, the joint has all the advantages of Type-H cable. Furthermore, and within the range of voltages where experience has not dictated the advantage (from the standpoint of the cable itself) of using soft or fluid jointing compounds with collapsible reservoirs, the carrying of the metal across the joint removes all stress from the compound, and there is no danger even if voids should exist. There is also of course no necessity for using reservoirs or otherwise maintaining the compound. Finally, even if a soft compound or fluid oil is used for the sake of the cable, there is always a possibility that the joint may be partially emptied of oil due to the improper functioning of reservoirs or other causes; and in this case, there will be a great advantage if all the jointing compound has been shielded from stress by metal wrappings.

I do not hold a brief for either type, but wish to emphasize that there are two types available, both of which have been eminently successful in service. I believe in general that Mr. Peterson's type of joint, in which the foil is not carried across the joint, would probably tend to give better laboratory tests than joints in which the foil is carried across, because the stresses are lower. From the practical standpoint, however, I feel sure that the metal foil should always be continuous through the joint, if hard or fairly hard joint-filling compounds are used, and that in case of fluid compounds with reservoirs, both types of construction should be carefully considered before a decision is made.

**R. G. Hooke:** At about the time Mr. Peterson started his development on high-tension cable joints, we were faced with a similar problem. Inasmuch as our solution of it is quite different from his, it seems that some of the details of the study which we have made and the results obtained may be of interest.

We first procured samples of several different types of three-conductor splices being used by various power companies. These were tested in the laboratory and at the same time careful analytical studies were made of the stresses which occurred in each. Mr. Peterson emphasizes the fact that in the past there seems to have been no regard for stress distribution or dielectric-constant relations of insulating materials and this was most certainly true in the majority of the specimens which we obtained. It would be impossible to agree too emphatically with the author's conclusion as to the harmful effects of porcelain spreaders, unreinforced crotches, and carelessly designed barrier tubes with high dielectric constants. By analytical comparisons, it is very easy to see the undesirability of such features.

In our work, we have developed certain methods, more or less empirical, for quick calculation of numerous instantaneous stresses in different parts of the joints and we find it very helpful to represent some of these by curves showing progressive changes in the conditions at different points in the splices, proceeding axially from one end toward the connector in the center. Illustrations of two of these charts will make their use clear.

The first illustration, Fig. 2, shows a joint in which conditions

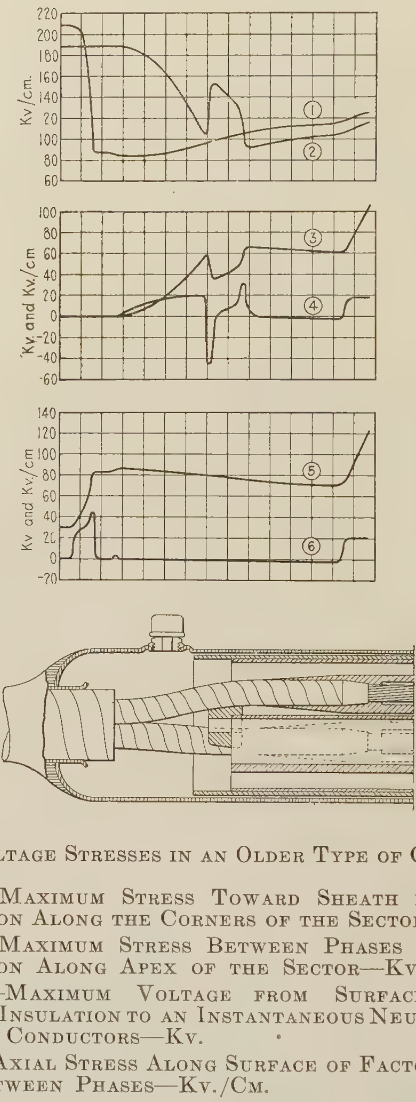


Fig. 2—Voltage Stresses in an Older Type of Cable Joint

Curve 1—Maximum Stress Toward Sheath in Factory Insulation Along the Corners of the Sector,—Kv./Cm.
Curve 2—Maximum Stress Between Phases in Factory Insulation Along Apex of the Sector—Kv./Cm.
Curve 3—Maximum Voltage from Surface of the Factory Insulation to an Instantaneous Neutral Plane Between Conductors—Kv.
Curve 4—Axial Stress Along Surface of Factory Insulation Between Phases—Kv./Cm.
Curve 5—Maximum Voltage on the Surface of Factory Insulation to the Nearest Point on the Sheath—Kv.
Curve 6—Maximum Axial Stress Along the Surface of Factory Insulation Nearest the Sheath—Kv./Cm.
Note: The Ordinate of Curve 4 is at all Points Proportional to the Slope of Curve 3, and the Same Relationship Exists Between Curves 6 and 5

were particularly bad. The very rapid decrease in the maximum gradient to ground, as shown by Curve 1 at the termination of the cable sheath, is an undesirable feature. Also, the "bump" in Curve 2, caused by the presence of the porcelain spreader between conductors, is an obvious point of weakness.

The next illustration, Fig. 3, indicates a very considerable improvement. In this case, the major irregularities are due to the abrupt terminating of a static shield around the three conductors. Elimination of these discontinuities is obviously simple

and curves result which are perfectly smooth except for conditions at the steps.

The irregularities on stepped or penciled insulation as shown in these figures require some explanation. The calculations are made along the surface of the original factory paper and therefore, at these points, abrupt increases of voltage necessarily occur due to the decrease in thickness of the factory paper and the consequent nearer approach to the conductor surface. These changes in potential cause the gradients shown, which are really in a radial rather than an axial direction; but they are plotted as part of the same curve as the axial stresses because they occur between adjacent surfaces of insulating material. Comparative

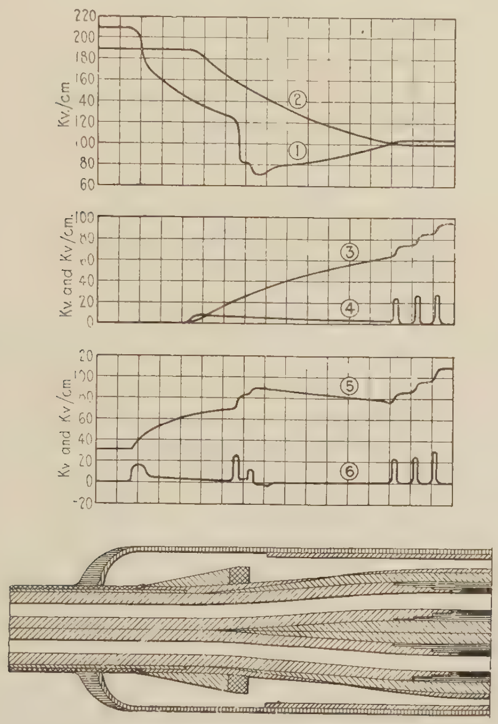


Fig. 3—Voltage Stresses in a Cable Joint of Recent Design

The Explanation of the Curves in this Case is Exactly the Same as for Fig. 2

effects of different numbers of steps or of different length pencils can readily be studied from these curves.

Of course the figures indicated on these charts are qualificative rather than quantitative, and of interest only in so far as they can be used for graphical indication of the differences between various designs of joints. However, when compared with the careful observations of conditions in the joints after the application on test of high potentials for periods of time up to several days, it was found that in a great majority of cases the weak spots were entirely determinable from analytic study made in advance of tests.

I mention these studies because I think that they emphasize the very great value of a scientific approach to the problem of cable jointing. In fact, so far as the electric field is concerned, splices are very much more complicated and require very much more careful mathematical analysis than does the cable itself wherein the assumptions of a homogeneous insulating medium can be made without appreciable error.

As a result of these studies a joint was determined upon in which the objective was to introduce as few foreign materials as possible. In other words, the more nearly we could make a splice an exact continuation of the cable, the better were we satisfied. With this in view, we concentrated our work upon joints insulated with hand-wrapped paper, the tape being carried well into the crotches at each end and cable compound being applied liberally during the operation. After the conductors have been insulated, the central filler space between the three conductors is filled with paper fillers, compound and jute. We have found it desirable to fill completely the inside crotches of the joint with paper fillers saved from the outside of the cable after the belt has been removed, it even being possible occasionally to thrust one or two fillers back for an appreciable distance into the cable itself. The outer spaces between the conductors and under the belt are also filled with jute and compound. Jute has been used since it is not feasible to obtain paper satisfactory for this purpose.

At first our procedure was to also fill the spaces between the connectors and the factory insulation with jute. Recently, however, we have adopted the use of wrappings of narrow varnished-cambric tape. In this connection, I am rather surprised at Mr. Peterson's practise of carrying the varnished cambric over the lower edge of his penciled factory insulation. He points out in numerous places the undesirability of having thin layers of low s. i. c. material in series electrically with rather heavier layers of high dielectric-constant insulation. It would seem from this consideration that he might experience an overstressing of the edge of his penciled paper, where it is under the varnished cambric, this being also immediately next to the conductor and therefore at a point where the gradients are at a maximum.

We have found that our workmen were much more successful in making steps than they were in cutting a pencil. For this reason, therefore, although the pencil gives the best theoretical stress distribution, we have adopted three steps on each conductor. In making the joint, the varnished cambric at the end of the conductor is not allowed to overlap any of the paper insulation. It is merely used as a filler, its superiority over jute being mainly that it is a higher grade material and less likely to contain foreign particles or moisture.

A paper belt is applied tightly over the three conductors with the fillers in place and over this is used a copper screen which carries the ground-potential surface completely across the splice and is held snugly against the paper belt by a wrapping of heavy wicking. The joint is filled under pressure with a light oil or grease and expansible reservoirs are used. This splice as nearly as possible, is a continuation of the cable and depends entirely for its strength upon impregnated, homogeneous, fibrous insulation.

Perhaps the most important difference between our splice and Mr. Peterson's is our use of hand-wrapped insulating material completely across the joint, whereas in the central part his splice he depends to a large extent upon the insulating value of the compound. The same feature is brought out in Mr. Peterson's remarks about joints on conductor-sheath cable; that he does not believe that it is desirable to carry the metal sheath of the conductors across the joint. He states that if the metal tape is carried across, the "joint would seem at first sight unsatisfactory * * * since filling compound is of no avail in taking up stress and the total voltage is applied to the comparatively weak path between pencil and hand-wrapped insulation." To us, this is by no means an obvious conclusion. In the first place, over the steps, the zero-potential surface in our joints, whether of the conductor-sheath type with the metal carried across the joint or of the belted type with the copper screen outside of the belt insulation, is very nearly identical with the lead sleeve of the joint. In other words, there is very small clearance between the lead sleeve and the built-up insulation about the splice. Therefore, unless Mr. Peterson uses a larger diameter of sleeve than ours, the leakage path in his joint, either from the connectors to the ground surface or between conductors, is practically the same as it is in ours. The reduction in the length of this path due to the use of the screen about the conductors is exceedingly

small. Secondly, there is one very important point in dielectric circuits which it seems to me Mr. Peterson does not sufficiently emphasize. It has been proved conclusively by a number of authorities that the breakdown strength of oil in volts per mil is very much greater for a thin film than it is if the material is not broken up into such films. Mr. Peterson accomplishes this division of the oil into films in his reinforcement of the crotch with varnished cambric, although he speaks of it as simply a replacement of the compound by a higher-strength material. It is actually both of these. However, the filling in of the space which he leaves free for compound between layers of fibrous insulation, in the middle of his splice between which would be distributed liberal amounts of oil or grease, should result in a definite increase in the breakdown strength of the joint at this point. As a matter of fact, some rather hurried and incomplete tests which we have made indicated that a direct puncture can occur from the connector to the sleeve on a splice made up as nearly in accordance with Mr. Peterson's design, as we are able to produce it, whereas, on numerous tests, no fault of this type or any other has ever occurred on joints of the kind which I have described and which we have adopted. The failures are invariably in the cable.

There are one or two questions which I should like to ask the author. He states that the cambric belt is punctured to allow oil to enter the cable where the fillers would normally be. Inasmuch as he does not carry the belt completely across the joint, we wonder that this puncture should be considered necessary. It would seem as if the compound would fill all of the spaces under the belt by entering through the empty filler spaces. Possibly his real objective is to provide an outlet for air bubbles which might collect under this belt insulation. Even this, however, would seem hardly necessary unless one end of the joint was appreciably higher than the other when it was being filled. The use of the static shield outside of the belt reduces to a safe value axial and circumferential stresses which might otherwise be harmful. We question, however, whether or not this shield *eliminates* the circumferential stresses in belted cable as is claimed. It certainly does maintain a zero-potential surface at a distance outward from conductors which is nearly equal to the distance from each conductor inward to the cable axis. This axis, however, for purposes of stress determinations, is not a zero-potential line. True, its *average* potential is zero, but at any instant its potential may not be zero. For example, assuming the three conductors to be carrying three-phase potential, if at a particular moment, the voltage of one conductor is zero, the voltages of the other two conductors will be opposite in sign and equal to 86 per cent of the crest value of the wave. Certainly, the geometric center of the cable would not then be at zero potential and for the moment, circumferential stresses about the conductors would exist. Determination of the magnitude of these stresses in a joint on sector-conductor cable using different types of splicing materials is exceedingly difficult. The fact seems to be that Mr. Peterson, by keeping his ground-potential surface nearer (than in the older joints) to the conductors, as each conductor is gradually moved away from the other two, has reduced the circumferential gradients to values which do not cause trouble; but these stresses are reduced only by virtue of the gradual transition from cable diameter to splice diameter, which is accomplished by the shield, the rate of transition being determined by the rate of separation of the conductors from each other.

We are inclined to question the author's reference to Conducell joints. We believe that the design of the Conducell barrier is excellent, if barriers are to be used at all and we should like to know whether or not Mr. Peterson tried reinforcing the crotches of the Conducell joints in the same way that he does his standard splice. We should expect this to improve greatly his test results on these joints.

In conclusion, I wish to say that the work which Mr. Peterson has done is extremely valuable. His joint is not difficult to make and it possesses a large number of very praiseworthy features. To me, one of the most interesting of these is the idea of a design which permits application of most of the hand-wrapped insulating material before the sweating of the connectors. With the ends of the conductors open, it should be very much easier to apply the insulation and also accomplish a considerable saving in time.

**F. A. Brownell:** We have tested a number of the author's cable joints between metal-sheath cables and between metal-sheath cable and belted cable, and have had one failure in the metal-sheath cable joint.

In each of the metal-sheath joints tested, evidence of overstressing was indicated by carbonized petrolatum at the end of the metal shield over the varnished-cambric cone and evidence of ionization at the lower edge of the cones.

In the joints where metal-sheath cable was joined to belted cable we found some evidence of overstressing at the surface of the conductors. This type of joint appears to be the best that has been offered for this type of construction.

We have been using the idea of the varnished-cambric cones for the past three years in making end-bells for testing cable in the laboratory, the only difference being that we apply two half sections of lead foil over the formed cone. We find that these sections can be applied in less time and eliminate more voids than the wrapping of narrow widths of foil.

Our test data on joints where the metal tape has been carried entirely across the hand-wrapped insulation are not in agreement with the author's. We have made numerous tests on this type of joint in the laboratory and have never broken down a joint nor opened one that has shown any indications of having been overstressed. In one test, failure occurred in the cable after 24 hours of testing at 125 kv. Another test at the same potential lasted for 20 hrs. with the failure in the cable. These tests do not compare with the author's test of 20 min. at 120 kv. Of the hundreds in service we have very recently had two failures.

To compare a joint for belted cable, we have tested and are now using the nearest thing to cable reconstruction that we believe is possible,—an all-paper joint with jute fillers, gauze stocking for shielding, and filled with the same oil as is used in the cable. This joint was designed a few years ago by Phillip Torchio, of the New York Edison Company, and is known as the Metropolitan joint. We have never broken down one of these joints on test. In one case we held 132 kv. for 25 hrs. when the cable failed. No evidence of overstressing was found in the joint.

We do not think it necessary to maintain the lay of conductors through the joint and we believe that another step in the art will be accomplished when phasing-out in manholes is eliminated.

**J. F. Fairman:** During the past five years an energetic program of cable and insulation research has been in progress in the Brooklyn Edison Company. The results, though by no means final or complete, have been very gratifying as reflected in the marked improvement in the performance of cable in operation. This improved performance is due both to better manufacture and to refinements in handling, jointing, testing, and maintaining cable by the operating company.

Mr. Peterson has discussed one of the more important contributions to improved operation made by the operating company in describing the evolution of our joint for multiple-conductor, high-voltage cable. I believe it is pertinent at this time to mention briefly another very important feature in this progress,—the installation of oil reservoirs on these joints.

In 1922 in the early stages of the redesign of the transmission system of the Brooklyn Edison Company, it was determined to make 27,000 volts the basic transmission pressure for future developments. Before placing this system in operation however, a great deal of consideration was given to the various factors of cable design and method of jointing and testing cables. Three fundamental factors essential to good performance of a cable system were brought out in this analysis: (1) Thorough initial

impregnation; (2) a means of assuring against the formation of voids after installation; and (3) the prevention of entrance of moisture. Good cable could be had at the factory and careful handling gave reasonable assurance against oil leakage and the entrance of air and moisture, but after a cable is in operation with the inevitable cycles of heating and cooling, there is migration and absorption of the compound which, although very slow, produces voids. Vacua of considerable magnitude have been found in cable, and any breaks in the lead sheath or imperfections in the wipe at a joint will allow air and moisture to be drawn into the cable or the joint.

As a result of this analysis, the Brooklyn Edison Company, at the initial installation of 27,000-volt cable in 1922, adopted the policy of installing oil reservoirs on the cable system in the hope of insuring a positive internal pressure above atmospheric pressure throughout the cable system at all times. It is obvious that with such internal pressure and a supply of oil for filling in voids, a break in the sheath would result in bleeding rather than the entrance of air or moisture. Loss of oil in this way could be detected by inspection of the reservoirs.

Such reservoirs were first installed in the stations at transformer and switch potheads. It was found that the migration of oil throughout the cable was so slow that these reservoirs on the potheads were not sufficient to maintain a positive pressure throughout any great length of cable. The next step was to install such reservoirs on a few feeders at the cable joints in the manholes, and the results obtained were so satisfactory that this practise is being extended gradually to the whole 27,000-volt cable system.

Two examples will serve to illustrate the results obtained. One feeder of old cable which had had a fairly good record as to failures, was taken out of service during a period of rearrangement. On testing it before putting it back into service, a number of failures both in cable and in joints, as well as the dry condition of the paper in the sections examined after failure, led us to make an experiment on this feeder. Oil-filled reservoirs were connected to each joint and it was put through periodic heating and cooling cycles for one month at low voltage and 150 per cent rated current. During this process 27 gallons of oil were absorbed, which is approximately equal to 1 per cent of the original compound in the cable. Then the feeder was tested. It went back into service without a failure in the cable, and has been operating steadily ever since. Another old feeder gave so much trouble that the operating voltage had to be reduced to 13,000 volts. Each joint was then equipped with a reservoir filled with oil and operation at 13,000 volts was continued for six months. Following this, it was tested for 27,000-volt operation and has given very satisfactory service at this voltage for over a year. To date 72 gallons of oil, which is approximately 2.6 per cent of the original compound, have been absorbed by this feeder from 120 reservoirs.

**W. F. Davidson:** Mr. Peterson has called attention to the tests which were made to determine the merits of joints in which metal foil was carried across the connectors and those in which it was cut off at some distance back from the connection. This suggests a point which seems to have received too little attention in connection with cable and joint specifications.

The significance of this was not appreciated until after considerable experimental work had been done. In the early stages it became evident that in order to secure prompt results it was necessary to use cable of superior quality so that the failures would occur in the joint rather than in the cable. However, when field construction work was started a new factor became noticeable.

The ideal condition in a joint or terminal, or for that matter in the cable itself, is to secure strictly radial stresses in the insulation which is under stress. But it is not always possible to do this in joints and terminals. Consequently, we are faced with the necessity of meeting more or less severe longitudinal stress. In their ability to withstand such stress, various cables show extremes of performance. I think it quite safe to say that the range of values obtained under these conditions is far greater than the range obtained with respect to radial stress. As an example, during some recent test on several samples of cable of the metal-foil type, it was found that with an end prepared in the manner described by Mr. Peterson, one sample could be operated for barely 30 hrs. at 120 kv. between conductors before failure occurred and even when it was possible to get failure of the cable under the lead, the ends almost invariably showed signs of severe longitudinal stress. In contrast to this, another sample of cable prepared in the same way and having the same insulation thickness, has operated for over 640 hrs. at 120 kv. without showing the slightest signs of stress.

Mr. DelMar has called attention to surface-tension effects and these probably explain some of the differences just noted. We might expect therefore to reduce troubles of this nature by making sure that the compounds used to fill the joint or terminal were of exactly the same character as that used in the cable itself so as to make a minimum surface tension along the boundary between the cable insulation and the surrounding medium. However, there are obvious and serious practical objections to such a procedure and it seems absolutely necessary to find some other solution to the difficulty.

Summarizing, I wish to urge the need for "jointable" cable. That means not only cable which can stand up under the bending and working essential to making a joint or attaching a terminal, but cable so constructed and impregnated that it has longitudinal as well as radial dielectric strength.

**Herman Halperin:** About two years ago tests were made in Chicago with the crotch of a 33-kv., three-conductor (sector) cable placed vertically in clear oil in a glass jar with a copper screen at ground potential inside the jar. The observations corroborate those made by Mr. Peterson in that spark discharges were observed across the film of oil in the crotch; but before this occurred, streamers were seen along the tape edges just above the end of the belt insulation. Some of these streamers ran around the conductors. It was found that such discharges could persist for about an hour at 120 kv., three-phase, without leaving visible signs of deterioration in the insulation, and before discharges across the oil in the crotch were noticed. It was also observed that bubbles of occluded air or other gases, which were seen clinging to the insulation previous to the application of voltage, would become dislodged upon the application of the voltage and flow upwards.

In the last page of Mr. Peterson's paper, it is stated that the joints were filled with petrolatum or oil. Experience in Chicago with petrolatum in three-conductor, 33-kv. joints has been unfavorable. About three years ago some 75 three-conductor 33-kv. joints filled with petrolatum at atmospheric pressure were installed. During the following winter several failures occurred in the crotch of the joints. The petrolatum was full of small voids or air spaces the size of a pinhead and had pulled away from the factory insulation of the conductors, causing void spaces around the conductor insulation in the crotch. Apparently the petrolatum contracted on cooling and pulled away from the mill insulation, and the maximum operating temperatures of about 20 deg. cent. were insufficient to melt the petrolatum which had a melting point of 30 deg. cent. Therefore it appears that if a hard or semi-hard compound is used its properties of adhesion to the cable and cohesion should be carefully chosen.

When these joints were rebuilt, they were filled with a thin oil (switch oil) and they gave entirely satisfactory service for the seven months when they operated at 33 kv., although in rebuilding the crotches were not reinforced.

Some experiments were recently started to reinforce the crotches on 500,000 and 650,000-cir. mil, three-conductor, 13-kv. joints. These cables have 9/64-in. insulation around each conductor, which is less than half the insulation on the cable used by

Mr. Peterson, and the conductors are considerably larger and stiffer than his conductors. These joints are to be filled with an asphaltic compound that has a Saybolt viscosity of about 750 sec. at 100 deg. cent., but to eliminate the variable introduced by the differences in filling obtained with the semi-hard compound used, oil was employed in these experiments.

The first joints were made with varnished-cambric tape applied around the conductors in the crotch in a fashion similar to that used by Mr. Peterson except that the foil was not used and, in addition, varnished cambric was applied around the three conductors. These joints were tested at 4.5 times the rated voltage for six hours, after which 10 per cent geometric increases were made every hour. The test results have been evaluated for the equivalent voltage for six hours. The joint with no reinforcement failed at nine hours, which test was equivalent to 69 kv. for six hours, using the 7th-root relation that has been developed for breakdown voltage—time characteristic of impregnated paper insulation. The corresponding voltage for the joint with the reinforcement was 75 kv., an increase of 10 per cent., but still failures were obtained in the joint. The failures were found in the crotch region at the end of the belt.

Later, insulation was applied to the conductors only and this was done either before or after the connectors had been sweated In the few tests that have been made, the joint with the reinforcement applied before the copper sweating has been found to be the stronger. The equivalent voltage for this joint for six hours is about 90 kv., which is 30 per cent better than that found for a joint with ordinary construction.

The fillers were left extending 3 or 4 in. into the joint, and after insulating, a couple of turns of twine were wrapped around the three conductors to hold the fillers in place. Cutting fillers, especially the central one, close to the end of the belt is liable to result in damage to the conductor insulation.

In the discussion of Mr. Simons' paper in the Winter Convention, Mr. Oesterreicher presented* some data on the beneficial effects of flared-out shields applied at the cable lead; and I am wondering whether Mr. Peterson has used anything of that nature on three-conductor joints.

The experience of the Commonwealth Edison Company is in thorough accord with the statement at the end of the paper, that such a joint (or any high-voltage joint) "depends quite largely on the ability of the splicers," and that "little difficulty is experienced in the field when men are properly trained."

**A. H. Kehoe:** Unanimous agreement will not be had to the statement that a decided improvement has been made over types of joints previously used.

It seems desirable to emphasize that only operating results in service are conclusive and that high over-voltage test methods may be wrongly interpreted. My experience with joint operation is that failures due to poor workmanship, several types of which are mentioned by the author canont be ignored. One of the most common causes of failure in operation apparently has been omitted; that is, "leaky wipes." Such workmanship defects are now the principal cause for joint failures, but, as stated by the author, compound-filling arrangements have reduced the number of these failures.

It does not seem wise to adopt a type of joint which requires very superior workmanship to make it successful, as compared to one in which ordinary careful workmanship will eliminate failure in service. This is likely to take place when high-voltage test results are used exclusively as a criterion for successful joint operation. They assume that factors of safety for all joint elements should have the same value, which is not required, particularly where the factory-formed type of joint insulation is one of the elements. The advantages of factory-formed insulation (the author mentioning Conducell, a well-known joint of this type) are evident in statistics of operation, and testing methods which give stress values beyond the breakdown values of certain of the elements do not demonstrate what the operating results will be if such values are never encountered.

Mention is made of the experiments with wooden spreaders. I can report on this that removal of all spreaders has resulted in a satisfactory mechanical joint and has eliminated an unnecessary element.

The author refers to confirmatory tests for metal-sheath cable which appear to be those made by the company with which the writer is associated. For joints on the metal-sheath type of cable, we have used a joint similar to that described in the paper. At present we know of no better way to make such joints, although possibly some improvement will be forthcoming which will reduce the workmanship hazard now ever present with the hand wrapping of three-conductor joints.

For the belted type of cable we doubt if operating results will show improvements over the factory-formed type, and so are continuing to use the latter. Experience has shown that both the time of making joints and their cost will increase by adopting the type suggested.

**T. F. Peterson:** Although practically all features of the joint described, together with the bases for design, have received favorable mention by one or another of those contributing discussion, there seems to be no general concurrence of thought or opinion. Possibly this is due to the fact that many have felt the call to defend joint designs with which they have had experience and there has been agreement of thought in just such measure as their designs are similar to the one in question.

Mr. Roper's report on the successful operation of single-conductor joints made up similar to the individual conductors of the joint described is very interesting and gratifying. His description of splicer's schools is quite timely and should serve to impress the importance of systematic training of men in the art of joint construction.

Mr. Eby has brought to our attention his early use of reinforcement of the insulation at the edge of lead sheath of single-conductor cable, overlaid with metal tape. While this means of relieving stress is highly commendable, it is felt that the use of varnished cambric (obtaining advantages of high strength and dielectric constant) instead of impregnated wick or cord, together with its use on three-conductor cable, is an advance. He feels that building up individual conductors of three-conductor belted cable is unessential electrically and cites his experience. This is not in accord with the results presented in the paper by me or in the discussion by Mr. Halperin. I dare say, that the use of built-up crotches of test sections in many laboratories, including the Electrical Testing Laboratories, is based on some such observation as the last mentioned.

Undoubtedly the combination of low-loss varnished-cambric tape and stepped insulation described by Mr. Eby is a very good one and might supplant the use of paper tape and conical pencil. However, difficulties with the latter are not so great as intimated. The work is rather quickly and quite accurately done, using a sharp knife and sand paper. The resulting surface is rough and when insulated presents no abrupt changes or finite discontinuities. Low-loss varnished cambric is a comparatively new development, and although it possesses many advantages, its use may not become general until there is more than one source of supply. This is the situation which dictates certain practises despite technical data pointing to the contrary.

The use of barriers for electrical reasons will be discussed later. At this time suffice it to say that in the joint described they are not needed for mechanical stiffening. Short-circuit tests of 20,000 amperes for several cycles have resulted in no appreciable movement of conductors.

Whether the tape of metal-sheath cable should be continued through the joint or not is a matter of concern to many. The reasons for maintenance of it are variously stated; for example:

*Journal, A. I. E. E., May 1927, p. 498.

1. Since the cable is so made—the joint should be.
2. Abrupt discontinuities and transitions are eliminated.
3. Voids may exist or the joint may drain without harm.

The first has no particular justification except in so far as there are incidental advantages which may accrue. The second is accomplished fairly well in the joint offered. As for the third, if voids in compound are expected, by all means short-circuit them. However, in the case of joints which may drain,—that is, lose their oil,—since these will probably fail eventually due to water, drying out or the like, this joint offers very little in favor of carrying the tape through. On the other hand, if conductors can be satisfactorily insulated with tape only, it would seem quite possible to cut down on hand wrapping when oil is brought into use. At least, the entire burden will not be placed on hand wrapping (with its uncertain personal element) but some part will be sustained by the oil.

Mr. Hooke has presented some very interesting data and ideas on joint design, stress distribution and dielectric circuit theory. The joint which he describes seems to be identical with the so-called Metropolitan type inasmuch as both are largely re-builds of cable. As such, considerable dependence is placed on the hand-made elements of the joint and as Mr. Kehoe points out, this is not always very desirable. In the early work in Brooklyn an attempt was made to eliminate hand operations entirely by insulating conductors with oil and barriers. When this failed, joints such as described were evolved. In these, the human element or personal equation is quite important so far as the hand wrapping is concerned. However, the oil serves as a second line of defense and renders inconsistencies in this less important.

Though Mr. Hooke has found a use for the Brooklyn Edison Company idea of thin strips of varnished cambric between connector and penciled mill insulation, he criticises the over-lapping of the latter with the tape and quotes my statements on the undesirability of having short paths of low specific inductive capacity material in series with long paths of high specific inductive capacity material. He has apparently overlooked the fact that in determination of stress distribution or values of gradients, the entire path from electrode to electrode must be considered to determine flux densities. These, multiplied by 1/s. i. c., give gradients. Obviously, a little varnished cambric (high s. i. c.) over a short path of mill insulation but having in series large amounts of oil, paper, etc. (low s. i. c.) cannot greatly alter the stress in the penciled insulation.

He also questions the use of a conical shield over the crotches of three-conductor belted cable, in eliminating circumferential stress. The basis for his argument is an attempted proof that the cable axis is not at zero potential. Given homogeneity and symmetry of position this must be the case when three-phase voltage is applied. I am at a loss to understand the reasoning in the case cited. When one conductor is at zero potential and the others at plus and minus 86 per cent of maximum potential, the locus of the zero-potential points is a plane half-way between the two conductors and perpendicular to their line of centers. Certainly the geometric axis of the cable falls on this.

Barriers in oil may be considered to produce beneficial results in two ways:

1. Where the free path in oil is broken up so as to reduce the distance in which ionization by collision may take place thus greatly increasing gradient for breakdown; for example paper and impregnating oil.

2. Where paths are long and breakdown is due to lining up of ions—water, impurities, etc.—barriers prevent this action and so increase the over-all strength.

There remains a range from approximately ¼ in. to about 2 in. in which the use of barriers is questionable. Their s. i. c. is usually high and since their thickness may be no small part of the total path of electric flux, the incidental shifting of stress in oil may more than overcome the advantage of barrier action. In view of this and since operating experience indicated that they were very ineffective in preventing failure where moisture or poor workmanship were present, barriers were eliminated entirely from the joint described. The breaking up of the oil space into very short paths, as is done in the Public Service joint by the use of filling materials, is quite permissible, although one might question whether this done under unfavorable conditions will furnish much of an improvement over the use of good oil.

I also doubt if many will subscribe to Mr. Brownell's idea on the elimination of phasing-out in manholes, although it would seem that this is greatly to be desired in view of the introduction of isolated-phase construction, installation of networks, etc. At any rate, does it not seem advantageous to phase-out in joints (rarely ever more than one in any one location) rather than subject one cable end at the pothead to twisting each time there is need for change?

Mr. Davidson's remarks are a fitting supplement to a paper on joints. Regardless of the type of cable or joint, the introduction of longitudinal stresses is inevitable at the pothead if at no other place. I join with him in a plea for a cable better able to withstand these stresses.

In response to the queries of Mr. Halperin I might say that due primarily to migration, considerable difficulty had been experienced with petrolatum-filled joints, but periodic refilling (at six-month intervals) almost entirely eliminated this trouble. As for the use of flared metal shields at crotches—several of these carefully made of spun brass were tried but the results were no improvement on those obtained with metal tape laid on the built-up conical structure.

# Discussion at Bethlehem

## CIRCUIT BREAKER DEVELOPMENT[1]

(Spurck)

Bethlehem, Pa., April 21, 1927

**W. H. Lesser:** I want to ask which is preferable, the multiple-break or the plain type of circuit breaker?

**R. M. Spurck:** The problem of economically producing interrupting capacity in an oil circuit breaker is fundamentally a problem of reducing gas formation. That breaker which produces the minimum amount of gas under any particular operating conditions is the most economical. Gas formation depends upon the total length and the total duration of the arc; that is, an arc two inch long will result in greater gas formation than an arc one inch long, first because more gas is formed per second; and, second, if speed of opening and all other factors are equal, the period of gas formation will be, of course, twice as long.

The company with which I am associated has produced the explosion chamber. The explosion chamber principle requires that the stationary contact be surrounded by an insulated metal chamber, totally enclosed save for the opening provided for the movable contact to enter and for several vent openings which are provided for certain specific applications. This explosion chamber is so arranged that a portion of the arc is drawn within the chamber, thus producing gas and thereby establishing a pressure in the chamber. This pressure increases the insulation of the gas because the disruptive strength of any gas increases with increase of pressure. The pressure also serves to force cool oil out of the chamber directly into the arc stream. The cool oil flowing through the arc path increases the dielectric strength of the gases in that path by reducing their temperature. Thus, in these two ways, the pressure

1. A. I. E. E. Journal, July, 1927, p. 707.

obtained by properly designed explosion chambers serves to increase the dielectric strength of the gases in the arc path beyond the values which obtain for the ordinary open break. This means that the contact separation required to oppose the voltage tending to reestablish the current is less; therefore, less gas is formed.

In multiple-break designs, individual arc length is not a linear function of the total number of breaks. In other words, if there are ten breaks, the length of arc at each break will not be one-tenth the length of arc for an equivalent single break. Instead, the total arc length for the ten breaks is much greater. The fact that the total length of contact of arc with the oil is greater for the multiple-break designs means that a greater amount of gas will be formed. This greater gas formation of the multi-break breaker is particularly noticeable when the ten plain-break breaker is compared with a breaker having two explosion chambers.

**J. T. Waugh:** I should like to ask Mr. Spurck if his company recommends an induction-type relay with their oil circuit breakers instead of current-transformer trip coils?

**W. P. Hearsmann, 3rd:** I believe that Mr. Waugh refers to the use of a dash-pot trip versus a separate device relay. Both were introduced for the purpose of adding a time-delay trip feature to oil circuit breakers.

We do not in general use the dash-pot trip, the reason being that, due to the change in the viscosity of oil and different expansion and contraction of the thin-walled cylinder and the comparatively heavy piston, the timing cannot be kept as accurately, perhaps, as it can be with an induction relay or with one of the solenoid and plunger type with an air bellows timing device which is generally used for simple relaying schemes.

**H. W. Osgood:** There is one feature of circuit-breaker rating pending which, if generally adopted, would work undue hardship on the purchaser. I refer to Rule 10692, recommended in October 1925 by the Electric Power Club and still under discussion by the N. E. M. A. This rule states in effect that manufacturers' published interrupting ratings of circuit breakers are not guaranteed.

What does this mean? In practise, the engineer of the prospective purchaser of switchgear prepares a specification stating the conditions under which the circuit breaker will be used and the maximum kv-a. which the circuit breaker should successfully interrupt, all terms and ratings being defined as stated in the standardization rules of the Institute. The manufacturer submits his proposal on switchgear to meet the purchaser's specifications and ties a qualifying string to the rating of the circuit breaker, based on the pending N. E. M. A. rule.

Two typical qualifying clauses presented by manufacturers were worded as follows:

"The Company does not guarantee or warrant the interrupting capacity of oil circuit breakers given herein."

"In the opinion of the Company the rating herein is reasonable under normal conditions and there are no implied warranties."

The equipment manufacturer is the one of the two parties involved who is well situated to determine what the rating of the circuit breaker is before it is offered for use. The purchaser does not generally enjoy this advantage.

It is recognized that the condition in which a circuit breaker is maintained is a large factor in its successful performance. When a machine fails however, the condition is given due consideration in determining responsibility for failure.

A reasonable procedure would be for the manufacturer to state the interrupting rating of his circuit breaker, defined according to the accepted rules of the Institute as to duty cycle, voltage condition and relation of current interrupted to the instant of short circuit and with the implied or stated understanding that the equipment was maintained by the user in reasonably good operating condition. The manufacturer then at least becomes a party to the discussion in case of failure of the equipment, whereas with the pending rule the manufacturer would be in position to disclaim responsibility if the equipment failed to meet the stated rupturing duty.

**John Grotzinger:** I am very much interested in the standardization of ratings. We ought to know definitely what we are buying, and we ought to be able to choose from different makes of circuit breakers those which are based upon the same rating, so that we can compare them upon the same basis and make the most economical selection.

**L. J. Gill:** I should like to ask Mr. Spurck what the clearance should be between contacts and other parts; for instance in a 22,000-volt, 150,000-kv-a. breaker. Also, what connection does system restoration voltage have to interrupting capacity in kv-a.?

**R. M. Spurck:** I cannot give clearances in inches because, as a general rule, the interrupting capacity of an oil circuit breaker is not a function of the minimum clearance to ground. The interrupting capacity is dependent upon other factors. The minimum clearance to ground is, fixed however, by the Standards of the American Institute of Electrical Engineers, which specify an insulation test, for one minute, of 2¼ times the rated voltage, plus 2000 volts. To meet this test, the designer may improve the shape of the electrodes, he may use linings of various insulating characteristics next to the tank, or he may surround the contacts with insulation. The absolute distance to ground required to meet the insulation test is, therefore, dependent upon the method of producing the required insulation.

The restoration voltage occurring in an oil circuit breaker after each zero of current is sometimes erroneously considered to be 58 per cent of the line-to-line voltage, because this is the value which a voltmeter connected from line-to-ground or from line-to-neutral would indicate under normal conditions on a three-phase system. The actual restoration voltage which occurs in an oil circuit breaker after each zero of current is not 58 per cent of the line-to-line voltage, but has been conclusively shown to be 87 per cent of that line-to-line voltage. If an oscillogram were taken with the instrument connected from line to ground, the reestablished voltage would be shown to be higher than the normal voltage by the ratio of 87 to 58. This value can be obtained on an actual system when a three-phase short circuit, not involving ground, occurs.

It is possible that Mr. Osgood and other engineers do not fully understand that the purchaser has stronger legal rights under a seller's contract obligation to deliver an oil circuit breaker having the interrupting capacity and other characteristics specified than he would have under a guarantee. The purchaser has no more assurance of getting what he orders under a guarantee than he has under the specifications without a guarantee. The principal effect of a guarantee is to impose liabilities on a manufacturer after the apparatus has passed out of his possession and control, liabilities which the manufacturer should not assume. As has already been pointed out in the discussion presented by J. D. Hilliard at 1927 Pacific Coast Convention at Del Monte, Calif., while the General Electric Company does not guarantee its breaker ratings it does stand back of its breakers, and will continue to do so.

At a joint meeting of the Oil Circuit Breaker Section of the N. E. M. A. and the Oil Circuit Breaker Subcommittee of the N. E. L. A. a year ago all of those present were unanimously agreed that a manufacturer could not guarantee interrupting capacities of oil circuit breakers because the interrupting capacity at any given instant depended upon system, maintenance and operating conditions which are entirely beyond the control of the manufacturer. The Oil Circuit Breaker Subcommittee of the N. E. L. A., therefore, unanimously agreed that three alternative

clauses be recommended to the manufacturers, but expressing a preference for the following clause:

"Because system, maintenance, and operating conditions are beyond the control of the manufacturer, interrupting capacities of oil circuit breakers cannot be guaranteed, but this does not relieve the manufacturer of his contract obligation to deliver oil circuit breakers having interrupting capacities as specified."

Acting on this recommendation of the Oil Circuit Breaker Subcommittee of the N. E. L. A., the General Electric Company adopted this clause as recommended. Under this clause, the company is bound by a legally enforceable contract to deliver a circuit breaker having the specified rating, and evidence that the circuit breaker does not have the rupturing capacity specified would force the company to either replace the circuit breaker with one having the specified rating, or become liable for damages for breach of contract.

There may be uncertainty in the minds of some manufacturers and some users as to the meaning of kv-a. interrupting capacity. Is it the interruption at unity power factor, or at approximately 90 deg. lag? Is it the interruption of the current on an otherwise isolated bus system, or is it interruption on a system having a connected load with shunt reactance and electrostatic capacity? Is it on grounded or ungrounded systems?

So far as the General Electric Company is concerned, and based on engineering information that has become available from field and testing department experience, the General Electric Company's published interrupting rating includes all the conditions above mentioned and this company will continue to publish ratings on this basis unless future development makes modification necessary, in which case, the published ratings will state that fact.

**Nicholas Smeloff:** On the second page I notice a list of voltages and rupturing capacities of breakers. Obviously not all of these breakers were tested. I should like to ask the designer whether the rupturing capacity of a circuit breaker can be determined quite accurately and be guaranteed? I don't mean guaranteeing in the sense of standing back of the breakers that are sold but a guaranty saying, "Yes, this breaker will open such a concentration of power," nor, in the present state of the art, is it necessary to actually test the break under laboratory conditions either in the factory or on a large system. We know that many breakers have not been tested; however, they are being quoted and it is being stated that they will interrupt such and such amperage or kv-a.

**L. W. W. Morrow:** The primary consideration in laying out large power systems is: What is the ultimate rating that we can expect in this "oil generator", (as Mr. Spurck puts it)? Certain systems have made us arrive at the conclusion that we are about up to the limit as regards the rating which can be expected of this type of breaker—about 1,500,000 kv-a. represents the limit.

I should like to know from Mr. Spurck if it is feasible and if he thinks it is practicable to consider designs of breakers of this character up to 5,000,000 or 6,000,000 kv-a. interrupting capacity, which is going to be the kv-a. required to be interrupted if present methods of laying out some power systems are to be continued.

The second feature which is appearing on the horizon is an entirely new approach to circuit-interrupting equipments and methods. Prof. Sorensen, of California Institute of Technology, presented a paper[2] a year ago in which he used a vacuum switch with copper electrodes to interrupt circuits. Contrary to theory and expectations, there was no pitting, and the circuit was interrupted at the first half-cycle. Experimentation is still going on which may or may not (we don't know today) lead to the development of a new method and new type of equipment for interrupting power circuits. I should like to have Mr. Spurck tell us what he thinks of such a development.

2. *Vacuum Switching Experiments at California Institute of Technology*, R. W. Sorensen and H. E. Mendenhall, A. I. E. E. Journal, December, 1926, p. 1203.

In all breaker design, the third interesting item which has not been brought out is the very marked development in speed of separation of contacts. In other words, five or six years ago, the number of cycles required to stretch out the arc before the current was interrupted was much greater than the cycles that are required today, due to the development of high speed in the separation of the contacts. I should like to know if Mr. Spurck thinks that we have reached about the limit in the speed possible in separation of contacts and if there is not an important function of the breaker's interrupting capacity to be measured in time of opening which involves not only the mechanism action but the energization of the relays which actuate the breakers also?

May not the development of the so-called electronic relays give us still further advantages in the operating time periods of these oil circuit breakers?

**R. M. Spurck:** Mr. Smeloff asks some questions about the interrupting rating of oil circuit breakers and wants some assurance of their reliability. Our data on interrupting capacity are based on empirical data which have been obtained from many thousands of tests in our own factory and have been checked by field tests. To my knowledge, no one has ever been able to calculate accurately interrupting capacity from the fundamental physical laws involved. As previously mentioned, gas formation is a factor. If we can determine the maximum amount of gas formed during a large number of tests under fixed conditions and if we can further determine how that maximum gas formation will vary as we vary the conditions, we shall have a wonderful instrument to use in calculating the interrupting capacity. It is obvious that such data can be obtained only from thousands of tests.

We have obtained such data from tests made in our factory, and the actual interrupting capacities of breakers designed in accordance with this compilation of data have been checked up to 750,000 kv-a. of interrupting capacity at 132,000 volts. We are now extending our facilities to have available within the next few months, a 100,000-kv-a. generator, designed to give a sustained short-circuit of 500,000 kv-a., to be used exclusively for oil circuit breaker testing. No doubt we shall then be able to increase the reliability of our higher interrupting-capacity ratings.

Mr. Morrow has asked several questions which I shall have to subdivide in order to answer clearly. First is the question of the limit of interrupting capacity. The answer to this is dependent upon the voltage which is to be considered. So far as interrupting capacity is concerned, we should have no great difficulty in obtaining any reasonable number of millions of kv-a. in the breakers of extremely high voltage,—for example, 220,000 volts. When, however, breakers in the 15,000-volt class are considered, the problem becomes more difficult because of the electromagnetic stresses and the burning of contacts which would result from the extremely high currents. Breakers having interrupting ratings of 2,000,000 kv-a. at 15,000 volts are now available. Such breakers must interrupt 80,000 amperes and must withstand 100,000 or 125,000 amperes for a short time. It is obvious that the contact burning and electromagnetic forces which may result from such currents must present formidable problems to the oil-circuit-breaker designer.

It is not desired to leave the impression that, were it necessary to design a breaker for even higher interrupting capacity, we should not attack the problem but—expressing a personal opinion—I do not believe it desirable to tie systems together in such a manner that two or three hundred thousand amperes of short-circuit current would be possible.

As already stated, the problem is less difficult when extremely high voltages are involved. In such oil circuit breakers the current effects are not serious because an interrupting capacity of 2,000,000 kv-a. means only about 5000 amperes at 220,000 volts as compared with the 80,000 amperes which must be interrupted to give the same kv-a. rating at 15,000 volts. Currents

very much higher than 5000 amperes must be encountered before the current effects become a serious factor.

Mr. Morrow's next question related to the vacuum switch as developed by Professor Sorensen in California. The development of switches of this type is still in its infancy. It is not unlikely that such a switch will eventually prove to be practical, but at the present time we have not sufficient data to predict definitely just where its field of application will be and how well it will perform.

The next question raised by Mr. Morrow is that of speed. This question naturally divides itself into two parts. The first is the actual speed of separation of the contacts and the second is the time between occurrence of the short circuit and the final extinction of the arc. Consider, if you please, the first question: The usual mechanical limit of the speed that can reasonably be obtained over a considerable distance is approximately 20 ft. per sec. The limit is, of course, imposed by the problems of accelerating the contacts sufficiently, and then retarding them at a rate which will not result in a severe shock or impact. For 15,000-volt breakers in the higher interrupting capacity class, the natural magnetic blowout effect of the 25,000 or more amperes obtained in the arc serves to extinguish the arc with only a relatively small separation of contacts. In this case, high speed of contact separation is not a very great factor. For the higher-voltage breakers it is true that an appreciable advantage would be derived from a high speed of contact separation, provided that such speed could be maintained throughout the total break distance finally required to extinguish the arc. It does but little good, however, to open rapidly for a short distance and then to decrease the speed of separation during the latter part of the arcing period, because it is during the latter part of the arcing period,—*i. e.*, when the break distance is greatest,—one that the rate of gas formation is greatest.

To consider the second part of the question,—that of getting the short circuit off the line quickly,—we find that we have had very little demand for such a characteristic. In most cases the attainment of selective operation requires that the short circuit be left on somewhat longer than the breaker requires to interrupt it. There have been some recent cases, especially for railroad work where inductive interference may be a factor, where arbitrary limits for short-circuit duration have been specified. These limits are considerably less than those usually established for central-station or industrial practise. Even these arbitrary limits may be met, but there is a question whether the benefit which might be secured in central station installations would justify the extra cost of obtaining these high speeds.

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# APPLICATIONS OF MECHANICS TO ELECTRICAL ENGINEERING

By Vladimir Karapetoff[1]

## Introduction

The author does not claim that the following list of applications of mechanics to electrical engineering is complete. Moreover, this list is not to be understood as a proposed program of what electrical engineering undergraduates should be taught in their course in mechanics. The list simply contains those problems in mechanics with which the author and his co-workers have come in contact during the thirty years of his professional activity in electrical engineering and electrophysics, including teaching, design, operation, consulting practise, research, study, and literary work.

*I. Electrical Machinery.*

Shafts subjected to a combination of torsion and flexure.

Critical speeds and whirling of shafts.

Unbalanced magnetic pull as an additional load on the shaft.

Mechanical stresses in revolving field poles, dovetails, etc.

Strength of revolving disks, solid and with holes.

Torque, speed, power, and energy in various units.

Retardation tests on electrical machines; gradual conversion of stored energy into losses; the law of retardation.

Expressions for the moment of momentum and stored energy of rotation, in terms of angular velocity and of moment of inertia; the question of units. Changes in momentum and in energy as a result of a given external impulse.

Centrifugal governors of hydroelectric units and their theory.

Hunting of synchronous machines; reduction of a machine to a pendulum; equivalent inertia, restoring force, and damping.

Noise and vibration of machinery; effect on surrounding structures.

Natural frequencies and harmonics of vibrating bodies.

Mechanics of lubricating oils and of bearings.

Motion of air and other gases used for cooling.

*II. Transmission Lines.*

The curve form of a conductor in a span; a catenary replaced approximately by a parabola.

Supports on equal and unequal heights; effect of temperature.

Stresses in an aerial conductor due to its weight, sleet, and wind.

Secondary stresses in special conductors, such as steel-core aluminum cables, duplex conductors, hollow-core conductors, hemp-core conductors, etc.

Stresses in a messenger cable supporting an electrical cable at intervals; double and single catenary construction; tie-off on curves.

Stresses in steel towers, concrete poles, and wood poles, with and without wind.

Unbalanced pull when one or more of the conductors are absent.

Stresses in the foundations for towers.

Stresser in crossarms, insulator pins, etc.

*III. Electric Railways.*

Train resistance, its elements and their variation with the velocity; acceleration and speed—time curves. Braking.

Energy input on acceleration. Energy storage in the parts moving on a straight line and in the revolving parts, such as the wheels and the motors. A pendulum as an acceleration meter.

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1. Professor of Electrical Engineering at Cornell University, Ithaca, N. Y.

Outline of a talk given on July 9th, 1927, Ithaca, N. Y., before the Summer School for Engineering Teachers, which is a conference on the teaching of mechanics, under the auspices of the Society for Promotion of Engineering Education.

Electric locomotives; suspended and non-suspended weights, link motions, connecting rods; their unbalanced forces and stresses; influence of the position of the center of gravity in nosing.

*IV. Mechanical Forces Due to Magnetic Fields.*

The magnitude of these forces is most conveniently derived on the principle of virtual displacements, and this principle can be best explained on a system of material points or on an elastic girder under load, so as not to complicate the treatment by electromagnetic quantities.

Busbars through which alternating currents are flowing behave like uniformly loaded beams and also vibrate at the synchronous frequency or a multiple thereof.

*V. Electromechanical Applications.*

Belting, rope, gears, silent chains, etc.; properties of springs.

Energy storage in large adjustable-speed driving motors used in steel mills and with mine hoists.

Starting and stopping of elevators and cranes.

*VI. Communication Engineering.*

Laws of vibration of diaphragms in telephone transmitters and receivers, automobile horns, etc. Nodes and harmonics; vibrational impedance.

Acoustics of buildings, resonating chambers, horns, etc.

Properties of sound waves.

Speech analysis.

*VII. Galvanometers and Oscillographs.*

Study of the motion of the coil in a ballistic galvanometer, as an example of a damped pendulum. Effect of the moment of inertia, torsion constant of the suspension, air friction, eddy currents, etc.

Laws of vibrating strings, resonance.

*VIII. Waves and Oscillations.*

An understanding of electric waves and oscillations is much facilitated by a previous study of mechanical waves and oscillations.

The following topics would help in particular: theory of the pendulum, resolution of an irregular periodic motion into harmonics; resonance and near-resonance; wave-motion in solids and gases; velocity phase and pressure phase; water waves in pipes and in open canals; different kinds of reflection.

*IX. Vector Analysis.*

Vector analysis plays an increasingly important part in electrical engineering and in adjacent branches of electrophysics. Its principles can be best learned in mechanics; first, because it is wonderfully effective there, and secondly, because the student deals with more tangible applications than with electric vectors. Coffin's *Vector Analysis* and Silberstein's *Vectorial Mechanics* are recommended to teachers who wish to familiarize themselves with the method. The following topics are of particular interest, as leading to corresponding electrical subjects:

Differentiation of vectors in deriving components of acceleration of a material point moving along a curved path;

Gradient and potential, in application to gravitation;

Concept of divergence, explained in application to hydrodynamics;

Curl explained in application to translation and rotation of a rigid body and to vortex formation in a liquid.

General equations of hydrodynamics of a perfect liquid, in the language of vector analysis, introducing velocity potential, conjugate functions, and mapping of lines of flow in two-dimensional problems.

*X. Theory of Elasticity.*

The general method of treatment used in the theory of elasticity is useful in the study of electrostatic and magnetic fields, preparing the student's mind both from a physical and formal mathematical points of view.

*XI. General Laws of Motion.*

Modern electronics is built essentially upon classical laws of motion of material points and rigid bodies, these laws being modified by the quantum hypothesis.

The following topics are useful in understanding modern works on the structure of matter:

Laws of motion of planets around the sun, because of their application to the structure of the atom.

General laws of motion under the influence of attractive or repelling centers.

Flight of a projectile subjected to various forces; application to moving ions and their deflection by electric and magnetic forces.

The gyroscope and its precession; this finds an application in the theory of atomic spectra.

A'Alembert's principle and analytical expression of constraints. Fundamentals of the calculus of variations and the principle of least action.

Lagrangian equations of motion and the Hamiltonian canonical form of equations; theory of astronomical perturbations and its modification in the theory of a complex atom.

*XII. Statistical Mechanics.*

In ionized gases and liquids, we have to consider a large number of discreet particles endowed with different velocities. They are dealt with according to the principles of the so-called statistical mechanics, which is a rapidly growing science, auxiliary to atomic physics. The best introduction into the subject is the classical kinetic (or dynamical) theory of gases, with its considerations of distribution of velocities of particles, probabilities of various kinds of collisions, elastic and inelastic, viscosity, Brownian movements, motion of a sphere in a medium consisting of bombarding particles, etc.

A useful topic is also that of partition of energy among various degrees of freedom of a mechanical system. This later leads to the principle of equipartition and to its failure in certain cases, thus preparing the student's mind to the quantum theory (or jumpwise changes in energy), with its applications to the problems of conduction, radiation, specific heats, etc.

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Changes of advertising copy should reach this office by the 15th day of the month for the issue of the following month.



## Regional Meeting in Chicago November 28-29-30

The second regional meeting of the Great Lakes District will be held in Chicago, Monday, Tuesday and Wednesday, November 28, 29 and 30, 1927. Convention headquarters will be at the Drake Hotel. The first day will be devoted to student activities and student papers and the following two days to the other features of the program.

Chicago offers to those attending the meeting exceptional opportunities for first-hand acquaintance with many of the newest and latest developments in the electrical art, as well as the attractions of a metropolitan city. In addition to the inspection trips arranged for the convention, plentiful opportunity will be offered to those whose interests lie in specific directions to see what they desire. Utility and manufacturing companies will be glad to receive visitors.

The program of the meeting covers subjects that at present are high in the interest of electrical engineers. After the student meetings of the first day, which will include a selection of papers on diverse subjects, there will be on Tuesday morning a symposium on single-conductor 132-kv. cable in which the economics, design, manufacture and use of this cable will be discussed authoritatively by leaders in this development. In the afternoon, electricity in railway and industrial applications characterizes the papers to be read. Power systems will engage the morning of Wednesday and electric communication the afternoon.

### Transportation

On account of its coincidence with the International Live Stock Show in Chicago attendants from some parts of the country may secure reduced railway rates. From Michigan, Ohio and Indiana, round-trip tickets will be available at one and one-half times the one-way fare. From points west and southwest of Chicago and from Wisconsin, round-trip tickets will cost one and one-third times the one-way fare. Members should consult their local ticket agents for complete information.

### Hotel Accommodations

All meetings will be held at the Drake Hotel. This hotel is located on the lake shore outside of, but close to, the business district of the city. The management of the hotel offers to the convention special rates of $6.00 per double room and $4.00 per single room, with bath in each case. The hotel will serve buffet luncheons during the convention at a special rate to delegates. *Reservations* should be made directly with the hotel and should be made early on account of the expected large attendance at the Live Stock Show.

The rates at other hotels in the vicinity of convention headquarters are given in the accompanying table:

HOTEL RATES

| Hotel | Location | Room rates per day (With bath) | |
|---|---|---|---|
| | | Single | Double |
| Drake*...... | | $4.00 | $6.00 |
| Eitel........ | Delaware and Rush Streets | 3.00 | 4.00 |
| Virginia..... | Rush and Ohio Streets | 2.50 up | 4.00 up |
| Devonshire.. | 17 East Ohio Street | 2.50 up | 3.50 up |

*Convention headquarters

### Inspection Trips

Arrangement has been made with the Illinois Central railroad for a special train to take visitors over the electrified system, stops to be made at control points, substations and shops. Other trips of inspection are arranged to generating stations, substations, manufacturing plants, steel mills and other major projects. Persons desirous of seeing installations not included in the schedule of trips may make special arrangements with the committee in charge.

### Dinner-Dance

On Tuesday evening the convention banquet will be held at the hotel. This will be informal. The dinner will start at 6.30 and dancing will be from 9 to 12. Immediately after the dinner there will be a short address by a speaker of national reputation.

### Registration

Those planning to attend the meeting are requested to notify J. E. Kearns, Chairman of the Hotel and Registration Committee, care of General Electric Company, 230 South Clark Street, Chicago, Illinois.

Immediately on arrival members and guests are urged to register so that inspection trips may be easily organized and banquet reservations made.

### Committees

The Regional Meeting Committee in charge of the meeting is as follows: B. G. Jamieson, Vice-President, District No. 5, Chairman; A. G. Dewars, Secretary; K. A. Auty, Treasurer; W. O. Kurtz, F. H. Riddle, J. T. Rood and H. E. Wulfing.

The local convention committees handling the phases indicated together with their officers are as follows: *General Committee*—B. G. Jamieson, Chairman, H. E. Wulfing, Vice-Chairman; *Papers & Meetings Committee*—P. B. Juhnke, Chairman, Herman Halperin, Vice-Chairman; *Hotel & Registration*—J. E. Kearns, Chairman, C. J. Schaus, Vice-Chairman; *Banquet & Entertainment*—C. W. Pen Dell, Chairman, W. F. Sims, Vice-Chairman; *Transportation & Inspection Trips*—L. M. Gumm, Chairman, L. J. Vanhalanger, Vice-Chairman; *Printing & Publicity*—

F. R. Innes, Chairman, H. S. Vaile, Vice-Chairman; *Student Convention*—J. F. H. Douglas, Chairman, C. M. Jansky, Vice-Chairman; *Finances*—K. A. Auty, Chairman.

**PROGRAM**

MONDAY NOVEMBER 28

Devoted to Branch Conferences and Student Technical Session. See Student Program on page 1293 of this JOURNAL.

TUESDAY MORNING

9.00 a. m. Registration.

9.15 a. m. Address of Welcome, B. G. Jamieson, Vice-President in Great Lakes District.

Symposium on 132-Kv. Single-Conductor, Lead-Covered Cable—H. W. Eales presiding.

(*a*) *Introduction—Economics and Commercial Demand*, P. Torchio, The New York Edison Company.

The demand and the field of use for the 132-kv. cable will be described with a discussion of its possibilities and limitations.

(*b*) *Theory, Design and Development*, L. Emanueli, Societa Italiana Pirelli.

The story of the development of the cable, joints and auxiliary equipment will be given. The design is of a new type embodying paper insulation maintained under a hydrostatic pressure of oil and operated at an electrical stress which is about double the previous maximum used in this country.

(*c*) *Manufacture, Inspection and Testing*, Wallace S. Clark, General Electric Company.

The new type of insulation required new methods of manufacture and many interesting tests.

(*d*) *Installation*, A. H. Kehoe, United Electric Light and Power Company; C. H. Shaw and J. B. Noe, the New York Edison Company; D. W. Roper, Commonwealth Edison Company.

The installation of a 12-mile line in New York and a 6-mile line in Chicago presented many unusual and difficult problems in underground cable work. These operating men will describe the peculiar features of these installations.

TUESDAY AFTERNOON

Buffet Luncheon.

2.00 p. m. Session on Railway Electrification and Industrial Application—B. J. Arnold presiding.

*Illinois Central Electric Operating Experience*, W. M. Vandersluis, Illinois Central Railroad.

In July 1926 the Illinois Central Railroad replaced 220 miles of steam-operated suburban train system in and around Chicago with a 1500-volt, d-c. system. The operating experience to date will be described.

*Operating Experience with 125-Ton Storage Battery Locomotive in Chicago Railroad Terminals*, Edward Taylor, General Electric Company.

This paper discusses the operating data of a 125-ton, storage battery locomotive used for switching in Chicago terminals.

*Operating Performance of Rectifiers*, Caesar Antoniono, Chicago, North Shore, and Milwaukee Railroad Company.

This paper deals with the results of practical application of the 600-volt, 1000-kw., mercury arc rectifier to interurban railway service and its adaptation to automatic operation. It is compared to the synchronous converter.

*Synchronous Motors for Steel-Mill Operation*, W. T. Berkshire, General Electric Company.

In the broadening application of the synchronous motor, it is now entering the field of the steel industry. This paper will describe its adaptation to such service.

TUESDAY EVENING

6.30 p. m. Dinner-Dance.

WEDNESDAY MORNING

9.15 a. m. Session on Power Systems—H. B. Gear presiding.

*The Chicago Regional Power System*, E. C. Williams, Public Service Company of Northern Illinois.

This paper contains a brief historical outline of the development of the electricity supply business in Chicago and vicinity, a description of the present system and a forecast of its future development.

*The Hall High-Speed Recorder*, E. M. Tingley, Commonwealth Edison Company.

The data obtained with the Hall recorder on the extensive 12,000-volt system in Chicago are given and discussed with over 60-cable failures tabulated.

*Relay Protection for Interconnected Systems*, L. N. Crichton and H. E. Graves, Westinghouse Electric & Manufacturing Company.

The rapid growth of complicated interconnected systems and networks has made the relay problem one of great importance. This paper will discuss recent developments in the use of relays.

*Alternator Characteristics Under Conditions Approaching Instability*, J. F. H. Douglas and E. W. Kane, Marquette University.

Performance curves under conditions of charging lines of considerable capacity are shown, including conditions producing pole slipping and a method of predicting performance is illustrated.

WEDNESDAY AFTERNOON

Buffet Luncheon.

2.00 p. m. Session on Communication—H. L. Hope presiding.

*Recent Developments in the Process of Manufacturing Lead-Covered Telephone Cable*, C. D. Hart, Western Electric Company.

This paper gives a discussion of the production of telephone cables on a very large scale and describes the recent advancements which have been made in the art.

*Telephone Toll Plant in the Chicago Region*, Burke Smith and G. B. West, Illinois Bell Telephone Co.

The growth of the telephone toll business in the Chicago region in recent years and some of the engineering and operating problems involved are described.

*A Two-Range Vacuum-Tube Voltmeter*, C. M. Jansky, Jr. and C. B. Feldman, University of Minnesota.

This paper describes the design of a vacuum-tube voltmeter suitable for measuring alternating voltages over a wide range of frequencies. Input impedance, methods of calibration, limits of accuracy and some possible uses are discussed.

*The Vacuum-Tube Rectifier*, J. H. Kuhlmann and J. P. Barton, University of Minnesota.

An oscillographic study of the effect of various filters upon the rectified current is given with a description of a method of measuring the small a-c. ripple in the rectified current by means of the vacuum-tube peak voltmeter.

## Special Meeting of Institute Membership

In accordance with an action taken by the Board of Directors on October 19, a special meeting of the Institute membership will be held at the Drake Hotel, Chicago, on Tuesday afternoon, November 29, 1927, at 2:00 o'clock.

The purpose of this meeting is to consider the adoption of a resolution which has been prepared by the counsel of the Institute and approved by the Board of Directors, authorizing an amendment of the Certificate of Incorporation of the Institute under which "the date for holding the Annual Meeting for the year 1928 shall be Tuesday, June 26, 1928 and thereafter shall be such date as shall be fixed in the By-laws."

The Annual Meeting is at present held in New York, N. Y., in May. A recent amendment to the Membership Corporation Law of the State of New York permits holding the Annual Meeting outside the State, and it is the intention of the Board of Directors, if the proposed change is approved by the membership at this special meeting, to arrange each year that the Annual Business Meeting shall be held during the Annual Summer Convention commencing with the Summer Convention of June 1928, in Denver.

## Future Section Meetings

**Cleveland**

*Automatic Train Control*, by Frank F. Fowle, Consulting Engineer. The meeting will be held in the Electric Rooms, Hotel Statler, at 8:00 p. m., November 17.

*Television*, by J. W. Horton, Bell Telephone Laboratories. The meeting will be held in the Electric League Room of the Hotel Statler, at 8:00 p. m., December 15.

**Erie**

Banquet. Joint with Technical Federation of Erie. Speakers: James Burke, Burke Electric Co.; Charles Milton Newcomb, Humorist, on "The Psychology of Laughter." November 15.

"The Romantic Development and Economics of Niagara Power," by W. K. Bradbury, Niagara Falls Power Co. December 20.

**New York**

"Predicting the Future for New York," by Bancroft Gherardi, National President, A. I. E. E.; R. H. Shreve, Shreve and Lamb, and President, New York Building Congress; C. E. Smith, Consulting Engineer; L. S. Miller, President, New York, Westchester & Boston Ry. Co.; James S. McCulloh, President, New York Telephone Co., and John W. Lieb, Vice-President and General Manager, New York Edison Co. November 4.

"Research and Research Men, by Dr. Willis R. Whitney, Director of Research Laboratory, General Electric Co., and C. F. Kettering, General Director, General Motors Research Laboratory. December 2.

**Pittsburgh**

*The Modern Oscillograph—The Analyst of the Unknown*, by J. W. Legg, Westinghouse Electric & Mfg. Co. November 15.

"Engineer vs. Salesman—Who's Ahead?" by G. M. Gadsby, President, West Penn Power Co. December 13.

**Pittsfield**

*Steam Power Plants*, by F. S. Collings. November 15.

**St. Louis**

*Public Utilities and the Public*, by L. H. Egan, President, Union Electric Light and Power Co.; E. B. Nims, President, Southwestern Bell Telephone Co.; Geo. B. Evans, President, Laclede Gas Light Co.; Rolla Wells, Receiver, United Railways Co. of St. Louis. November 16.

*Railroad Electrification*, by J. B. B. Duer, Elec. Engr., Pennsylvania Railroad, Altoona, Pa. December 21.

**Vancouver**

*Oscillograms*, by Dr. H. Vickers. December 6.

## A. I. E. E. Directors' Meeting

The regular meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Wednesday, October 19, 1927.

There were present: President Bancroft Gherardi, NewYork; Vice Presidents H. M. Hobart, Schenectady, G. L. Knight, Brooklyn, A. E. Bettis, Kansas City, J. L. Beaver, Bethlehem, A. B. Cooper, Toronto; Managers J. B. Whitehead, Baltimore, J. M. Bryant, Austin, Tex., E. B. Merriam, Schenectady, M. M. Fowler, Chicago, H. A. Kidder, New York, I. E. Moultrop, Boston, H. C. Don Carlos, Toronto, F. J. Chesterman, Pittsburgh, E. B. Meyer, Newark, N. J., H. P. Liversidge, Philadelphia; National Secretary F. L. Hutchinson, New York.

Reports were presented of meetings of the Board of Examiners held September 14 and October 5, and the actions taken at those meetings were approved. Upon the recommendation of the Board of Examiners, the following actions were taken: 99 Students were ordered enrolled; 46 applicants were elected to the grade of Associate; 46 applicants were transferred to the grade of Member.

Approval by the Finance Committee for payment, of monthly bills amounting to $36,305.70, was ratified.

A budget for the appropriation year beginning October 1, 1927, was adopted as prepared by the Finance Committee.

In accordance with the provisions of the Constitution, Messrs. Will D. Ray and Thorburn Reid were made "Members for Life" by the remission of future dues. The former has been a member of the Institute for thirty-five years, and the latter for thirty-seven years.

The Secretary reported 1187 members in arrears for dues for the fiscal year which ended April 30, 1927, and was authorized to remove from the membership list on December 1, 1927, all of those whose dues for that year remain unpaid at that time and who have not requested an extension of time for the payment of these dues.

Five members of the Board of Directors were selected to serve on the National Nominating Committee, as follows: Messrs. H. C. Don Carlos, B. G. Jamieson, H. A. Kidder, G. L. Knight, and H. P. Liversidge.

Complying with the request of the officers of the Pacific and North West Districts, the Board adopted a resolution authorizing those two Districts to hold their annual Student Activities Conferences jointly, during the Pacific Coast Convention each year, instead of separately, traveling expenses at the rate of ten cents per mile one way to be paid from the Institute treasury.

Upon the recommendation of the Committee on Coordination of Institute Activities, the following schedule of meetings was adopted for the year 1928, the exact dates in some instances to be determined later.

| | | |
|---|---|---|
| February 13-17 | Winter Convention | New York City |
| March | Regional Meeting | St. Louis, Mo. |
| April | Regional Meeting | Baltimore, Md. |
| May | Regional Meeting | New Haven, Conn. |
| June 25-29 | Summer Convention | Denver, Colo. |
| August or September | Pacific Coast Convention | Spokane, Wash. |
| October or November | Regional Meeting | Atlanta, Ga., or elsewhere in Southern District. |

The Secretary reported that in accordance with the Board's action at its April 1927 meeting, he had obtained from the counsel of the Institute advice as to the necessary procedure to change the date and location of the Annual Business Meeting of the Institute to permit of holding it outside of the City of New York and during the annual Summer Convention; and as the first step in the required procedure the Board adopted a resolution calling a special meeting of the Institute, in Chicago, Illinois, November 29, 1927, at 2:00 p. m., (during the Chicago Regional Meeting), for the purpose of considering and authorizing an amendment of the Certificate of Incorporation of the Institute changing the date of the Annual Meeting.

The following amendments to the Institute By-laws were adopted:

Sec. 31. Substituted the following for the present section:

"Sec 31. Each District Executive Committee shall appoint a small continuously functioning Coordinating Committee consisting of the Vice-President and District Secretary, ex-officio, and four additional members of the Executive Committee and one Student Branch Counselor who shall serve for a term of one year. The four Section officers and the Counselor shall be eligible for reappointment if they are members of the Executive Committee and Counselor respectively during the following year. This Coordinating Committee of seven shall function continuously, in an advisory and cooperative capacity only, with the Meetings and Papers Committee, Institute headquarters, all Sections of the District, similar committees of other Districts, and the Sections Committee, for the stimulation and preparation of papers of a high grade."

(To clarify the language and to add a Student Branch Counselor to the District Coordinating Committee.)

Sec. 32. In the first sentence of the second paragraph, changed "seven" to "nine" and "five" to "seven," so that the sentence reads as follows:

"Upon expression by a District Executive Committee of a desire to hold a regional meeting, and approval by the Board of Directors, the responsibility for the meeting shall rest with a Regional Meeting Committee of nine, composed of the seven members of the District Coordinating Committee and two additional members representing the Section in which the meeting is to be held." (The rest of the paragraph to remain the same.)

(To conform with amended SEC. 31.)

SECS. 48, 50, 54-56. (Covering Students and Student Branches.)

To make eligible for Student Enrolment in the Institute those students who are registered in the general engineering curricula, but who expect to take up the study of electrical engineering—to meet the condition in institutions of recognized standing in which a student wishing to study electrical engineering must register in a curriculum bearing the name of "general engineering" or simply "engineering."

SEC. 48. Replaced first sentence by:

"Any person registered as a full-time student in a university or technical school of recognized standing who is pursuing a regular course of study in preparation for the profession of electrical engineering may be enrolled as a Student of the American Institute of Electrical Engineers."

Second sentence: no change.

Third sentence: (1) Replaced the word "giving" by the word "providing"; (2) deleted the word "electrical"; (3) replaced the word "course" by the word "curriculum."

(The word "curriculum" substituted for the word "course" because the latter is frequently used to designate the work given in a particular subject.)

SEC. 50. Fourth line: Replaced the words "graduation from" by the following: "award of the baccalaureate degree."

(For the purpose of making clear the fact that the period of enrolment terminates one and one-half years after the award of the baccalaureate degree, and cannot be considered as terminating one and one-half years after the award of a degree for graduate work.)

SEC. 54. First line: Deleted the word "electrical"

Third line: Deleted the word "electrical."

Ninth line: Replaced the word "electrical" by the word "engineering."

Tenth line: Deleted the word "electrical."

SEC. 55. Second line: Replaced the word "course" by the word "curriculum."

Third line: Deleted the word "electrical."

SEC. 56. Fifth line: (1) Deleted the word "electrical;" (2) Replaced the word "course" by the word "curriculum."

SEC. 73. First sentence: Added the word "the Meetings and Papers Committee of the previous year," changing the sentence to read as follows:

"SEC. 73. The Committee on Award of Institute Prizes shall consist of the chairman of the Meetings and Papers Committee, acting as chairman, and the chairmen of the Publication Committee, the Research Committee, the Meetings and Papers Committee of the previous year, and the chairmen of such other committees as the Board of Directors may designate. This Committee shall award the prizes established by the Institute in accordance with the details of procedure adopted by the Board of Directors."

(This change is required by the revised prize policy adopted by the Board of Directors June 23, 1927.)

Consideration was given to recommendations of the Publication Committee covering changes in the style of publication of the annual TRANSACTIONS and the abridgment of papers for publication in the JOURNAL, and the Board directed that a notice to the membership regarding these proposed changes, with a request for comments, be published in the November JOURNAL.

The following appointments of Institute representatives were made: Mr. H. A. Kidder appointed to Board of Trustees of the United Engineering Society, for term of three years commencing in January 1928, succeeding Mr. B. Gherardi, whose term expires at that time; Mr. Gano Dunn reappointed on Engineering Foundation Board, for term of three years commencing in February 1928.

Mr. Frederick M. Servos was appointed Local Honorary Secretary of the Institute for Brazil, to fill the unexpired term, ending August 1, 1928, of C. M. Mauseau, who has resigned this position on account of removal from Brazil.

The Joint Conference Committee of the Founder Societies (Presidents and Secretaries of these societies) reported consideration of a communication to the Secretaries of the societies from American Engineering Council, calling attention to the proposed national observance of the 200th Anniversary of the Birth of George Washington to occur in 1932, and suggesting organized participation in this celebration by the engineering and allied technical societies as a proper tribute to Washington, who was an engineer. The Joint Conference Committee had adopted a resolution recommending to the governing bodies of the Founder Societies "that each society appoint one representative on a joint committee to give consideration to the Washington Celebration in 1932 and recommend to the governing bodies such action as the committee deems desirable regarding the participation by the societies in the proposed Celebration." The Board concurred in this resolution and authorized the President to appoint the Institute's representative on the proposed joint committee.

Upon the recommendation of the Joint Conference Committee, the Board voted that an invitation to participate in the proposed World Engineering Congress, Tokio, Japan, in 1929, be accepted on behalf of the membership of the Institute and the President authorized to appoint a representative on a joint committee of the Founder Societies to take such steps as appear desirable and to serve as a nucleus in the formation of an American Committee on Participation in the Congress.

An invitation to be represented by two delegates at the celebration of the Centenary of the Incorporation of the Institution of Civil Engineers (Great Britain), to be held during the week beginning June 3, 1928, was accepted, and the President was authorized to appoint the delegates.

Other matters of importance were discussed, reference to which may be found in this and future issues of the JOURNAL.

## World Engineering Congress in Japan in 1929

A World Engineering Congress will be held at Tokio for a period of two weeks during the latter part of October 1929. Baron Shiba, as the official representative of fourteen Japanese technical societies, reported at a recent luncheon at the University Club, New York, that definite progress in preparation for the Congress was now being made. He received the assurance of American support from the group of engineers present, representing the national engineering societies, industrial and utility executives, and consulting engineers.

The preliminary plans for the congress cover some seventeen different divisions as follows: General problems, including education, administration, management, statistics, standardization, international cooperation; engineering science; public works; communication and transportation; power; architecture and structural engineering; mechanical and electrical engineering; chemical industry; textile industry; shipbuilding and marine engineering; aeronautical and automotive engineering; mining and metallurgy; engineering materials; fuel; water works, drainage, heating, ventilation, illumination, refrigeration; scientific management.

At the meeting of the Board of Directors of the American Institute of Electrical Engineers on October 19th the following action was taken:

VOTED: That the invitation to participate in the Wold Engineering Congress, Tokio, 1929, be accepted on behalf of the membership of the Institute and the President be authorized to appoint a representative on a joint committee of the Founder Societies to take such steps as appear desirable, and to serve as a nucleus in the formation of an American Committee on Participation in the Congress.

## Researchers in Dielectrics Requested to Report Problems They are Studying

Every person conducting research on dielectrics is requested by the Division of Engineering of the National Research Council to tell that body the *specific problems* on which he is working. All information received in this way will be tabulated and used by the Committee on Insulation in this Committee's efforts to coordinate research in this field and thus eliminate unnecessary duplication. The information should be sent to the Division of

Engineering, National Research Council, 33 West 39th Street, New York, N. Y.

Many benefits should result if this information is collected and made available. Wasted effort from duplication of work will be eliminated, problems not receiving consideration will be pointed out, and the store of knowledge on the subject will increase much faster if opportunity is thus given for coordinating research programs.

## William B. Woodhouse in the United States

William B. Woodhouse, Past-President of the Institution of Electrical Engineers of Great Britain, has recently visited Canada and the United States with the object of noting the developments in the electrical industry. His trip included Quebec, Montreal, Buffalo, Detroit, Chicago and New York.

On Tuesday, October 25, a luncheon was given in his honor by President Gherardi at the Railroad Club, New York, which was attended by eight past-presidents of the Institute and some of the present officers. Brief informal addresses were made by Messrs. Gherardi, McClellan and Pupin, and an interesting response was made by the guest of honor.

The occasion was very enjoyable to all present and will tend to strengthen the friendly relations already existing between the two organizations representing the electrical engineering profession in Great Britain and America.

## Edward Dean Adams Represents American Engineers at Fifth Centenary of Louvain University

The University of Louvain, which was one of the first in Europe to give attention to the natural sciences, has just celebrated its 500th anniversary with brilliant ceremonies, and in these ceremonies, the engineers of America have participated through the spokesmanship of Doctor Edward Dean Adams, who was chosen as their representative. For forty years, during the French Revolution and the Napoleonic wars, the doors of the university were closed. It reopened however, in 1835 and its faculty of science was established, attracting by its research work many students and professors from all over the world. Its colleges of engineering and science grew and did excellent work until devastated by the World War, when the great library was totally destroyed by fire; but the buildings are now being restored and enlarged through the collaboration of national resources and the assistance of the United States and other countries. Under the auspices of an American committee with President Butler of Columbia chairman, and the leadership of Mr. Whitney Warren a New York architect, a new library building has been designed and is being erected with money contributed by hundreds of thousands of Americans. Nickels and dimes from more than half a million school children and teachers; gifts of from $1.00 to over a hundred thousand from students of practically every college, university, academy and preparatory school; city departments, foundations and individual have contributed to this important undertaking. Doctor Adams represented 56,000 American engineers to a distinguished assembly of the nations royalty and dignataries of both state and nation. Keen interest was manifested in the development and maintenance of this permanent joint activity for scientific achievement, stimulated by the work in individual fields of research. The tower of the new building will be designed for a four-dial clock and carillon—a perpetual reminder of the good will of the American people. Another ceremony typifying the support of the four founder societies was the planting of four California redwood trees,—seedling Sequoia Gigantea,—in front of the new engineering building. This ceremony was performed by Doctor Adams and his grandson, Kempton Adams.

## Bureau of Standards' New Grouping of Activities

An important change in the administrative organization of the Bureau of Standards, which it is believed will make for increased efficiency through a better grouping of the Bureau's numerous activities, was announced today by the Director, Dr. George K. Burgess.

Under the new arrangement Dr. L. J. Briggs has been appointed Assistant Director in charge of research and testing, while Mr. Ray M. Hudson becomes Assistant Director in charge of commercial standards.

## Award of John Fritz Medal for 1928

October 21, the John Fritz Gold Medal for 1928 was awarded to General John J. Carty, of New York, Past-President of the Institute for achievement in telephone engineering.

This annual award was made unanimously by the Board of sixteen representatives of the American Societies of Civil, Mining and Metallurgical, Mechanical, and Electrical Engineers, having an aggregate membership of 57,000.

This medal is awarded not oftener than once a year for notable scientific or industrial achievement, without restriction on account of nationality or sex. It is a memorial to John Fritz, late of Bethlehem, Pennsylvania, long a leader in the American iron and steel industry.

This is the 24th award. A few of the Medalists are Elmer Ambrose Sperry, for development of the gyroscope; Edward Dean Adams, for achievement in development of hydroelectric power at Niagara Falls; John F. Stevens, for achievement in planning and organizing for the construction of the Panama Canal, building of railroads, and administration of the Chinese Eastern and Siberian Railway during and immediately after the World War; Ambrose Swasey, as a designer and manufacturer of instruments and machines of precision, a builder of great telescopes, and the Founder of Engineering Foundation; Senator Guglielmo Marconi, for invention of wireless telephony.

The members of the Board which awarded the Medal for 1928 were:

Charles F. Loweth, Chief Engineer, C. M. & St. P. Railway.
C. E. Grunsky, Consulting Engineer, San Francisco.
Robert Ridgway, Chief Engineer, Board of Transportation, New York City.
Geo. S. Davison, President, Gulf Refining Co., Pittsburgh.
Arthur S. Dwight, President, Dwight & Lloyd Companies, New York.
William Kelly, Mining Engineer, Iron Mountain, Michigan.
J. V. W. Reynders, Consulting Engineer, New York.
Samuel A. Taylor, Consulting Engineer, Pittsburgh.
Fred R. Low, Editor, *Power*, New York.
W. F. Durand, Professor, Mechanical Engineering, Stanford University.
Dexter S. Kimball, Dean, College of Engineering, Cornell University.
Charles M. Schwab, Chairman, Bethlehem Steel Corporation.
Gano Dunn, President, J. G. White Engineering Corporation, New York.
Farley Osgood, Consulting Engineer, New York.
Michael I. Pupin, Professor, Electro-Mechanics, Columbia University.
C. C. Chesney, Manager & Chief Engineer, General Electric Company, Pittsfield, Mass.

The presentation of the Medal will take place in February, 1928, in connection with the Winter Convention of the American Institute of Electrical Engineers, in the Engineering Auditorium, 29 West 39th Street, New York. The Medal will be presented to General Carty by Robert Ridgway, Chairman of the Board which made the award.

## ENGINEERING FOUNDATION

### EXCEPTIONAL RESEARCH PROBLEMS

Since 1914, when Ambrose Swasey established the Engineering Foundation, the idea of such a national research institution has gained ground steadily and surely. The income from the Foundation which in 1915 was $5000, has increased to $30,000; Mr. Swasey's several gifts totaled $500,000; there has been $50,000 from Henry R. Towne, $50,000 from Edward Dean Adams, and $10,000 from Seeley W. Mudd. In connection with the cooperative projects in which the Foundation has participated, many donations of equipment, materials for research, services, and money have been made and several wills of persons still living are known to contain bequests.

It is pertinent to inquire what advantage for research the Engineering Foundation enjoys over individuals and business organizations? In general, the advantages are similar to those which the Rockefeller Foundation possesses in its well-known work of safeguarding health. They are, briefly, the advantage of long views and broad purposes; easy cooperation with other institutions; not having to produce a profit; conservation of funds, continuity of service, and unified direction by experienced trustees, flexibility of purpose, and the prestige of the four founder engineering societies.

There are too specific advantages for effective research possessed by Engineering Foundation. In modern engineering, numerous problems are constantly arising which no individual nor industrial corporation feels justified in attacking, not having the time, equipment, nor ability to conduct a particularly difficult piece of research. Frequently a company hesitates to take up, single-handed, a problem to the solution of which a dozen or a hundred companies should contribute but for which no one wishes to take the lead. In such a situation, Engineering Foundation steps forward as a detached, non-commercial party, and invites cooperation.

Sometimes there are doubts and obscurities of technical procedure which are positively harmful, but which no individual or company feels it a duty to clear up. Such conditions arise in modern industry as a consequence of rapid changes and adjustments and the extremely diversified and disjointed nature of America's tremendous engineering undertakings. Leadership out of such predicaments can best be initiated by an agency like Engineering Foundation. It is to the best interest of the country's industries, not to mention the interests of the engineering profession and the public at large, that such a free, unbiased institution exist to act as a clearing house for engineering research.

More detailed examples of the policy and accomplishments of Engineering Foundation will be given in a later article. In the dozen short years of its history it has been as active as any of its sponsors could wish. There will always be plenty of opportunity for it to exercise its functions, even when its endowment reaches the $5,000,000 that it hopes to attain.

P. B. McDonald.

## Engineers' Club of San Francisco Dedicates New Headquarters

On Friday evening, September 30, the Engineers' Club of San Francisco formally dedicated a well-equipped and very attractive new home at 206 Sansome St., San Francisco. As an organization, the Club cooperated in every way not only with the local section but with the many sections of engineering societies. Its headquarters has become the gathering place for uncheon and evening meetings.

## A. S. M. E. Annual Meeting

On December 5-8, The American Society of Mechanical Engineers will hold its Annual Meeting at the Engineering Societies Building, New York, N. Y. Machine shop practise will occupy the opening sessions; there will be also considerable data presented upon railroad subjects, fuels, the handling of materials, photography, management, aeronautics, central power stations and research will also occupy important places upon the interesting program which the Society has planned for its members and guests. At the final session, Thursday afternoon, Dec. 8, the Henry R. Towne Lecture will be given by T. S. Adams, Professor of Economics at Yale University.

## A New Ultra Violet Ray Machine

A device that has been called "a machine with a moral sense" because it will detect erasures on checks, show up bootleg whiskey in its true colors, expose art forgeries and imitation gems and do almost everything except make arrests, is one of the wonders which attracted attention at the Electrical and Industrial Exposition, held at the Grand Central Palace, October 12 to 22.

This is a new ultra violet ray machine being demonstrated by Dr. Herman Goodman, a member of the Illuminating Engineering Society. No false object seems to be able to withstand its searching scrutiny.

Dr. Goodman states that the principal purpose of his experiments has been to seek the forms of glass best adapted to the transmission of the full health-giving violet rays which are in the sunlight. He states that some forms of glass, said to transmit the rays, are less than 40 per cent efficient, but there are some expensive quartz glasses which allow for its full transmission.

The principle upon which this apparatus operates is that the invisible light which scientists know as ultra violet causes fluorescence to appear in a great many substances and changes the appearance of others. Consequently, when a great volume of ultra violet light is generated through a mercury vapor arc in quartz and then passed through a special filter, which cuts out all but the deep violet and invisible rays, it makes visible that which cannot be seen with the naked eye.

## PERSONAL MENTION

F. Krug, was appointed General Manager of the Porto Rico Railway Light & Power Company, effective September 1st.

Harry Diamond has resigned from the teaching staff of Lehigh University to take up work as Associate Radio Engineer at the Bureau of Standards, Washington, D. C.

C. O. Mailloux, Past President of A. I. E. E. was an appointed observer at the Congress of the International Confederation of Intellectual Workers at Paris, September 26 to 29.

Clovis M. Converse, former Manager of the Power Apparatus Department of the Great Northern Electric Appliance Company, St. Paul, Minn., has been made its Sales Engineer of the G. & W. Electric Specialty Co.

L. B. Wilmot, who from 1920 to 1926 was carrying on a private consulting practise in South Africa, is now consulting mechanical engineer to the Anglo-American Corporation, Ltd., Northern Rhodesia, Africa.

Frank E. Pitt, who was District Engineer for the South Wales Electrical Power Distribution Company, Ltd., Cwmbran, England, has joined the Lancashire Electric Power Company as District Mains Engineer.

Stanley S. Seyfert, Associate Professor of Electrical Engineering, Lehigh University, Bethlehem, Pa., is spending a year's leave-of-absence at the Massachusetts Institute of Technology in study and research.

William G. Houskeeper announces his resignation from the Technical Staff of the Bell Telephone Laboratories, Inc. Two

years ago Mr. Houskeeper received the John Scott Medal for his work on sealing base metals to glass.

W. E. Doty, formerly associated with the Brunswick-Balke Collender Co., Omaha, Neb., in radio and electrical reproduction work, has accepted a position as Research Engineer with the Sanitation Equipment Company, Battle Creek, Mich.

Yasudiro Sakai, Consulting Electrical Engineer and Registered Patent Attorney, Tokyo, Japan, has been appointed by the Imperial Government to serve as a member of the Examination Committee for the Admission to Patent Attorneyship.

Henry Logan, who previously had charge of the Cleveland Office of the Holophane Company, has returned from his professional survey of European lighting developments and is now Manager of a new Consulting Department in the New York Office of this company.

D. J. Moulton-Redwood has recently joined The General Motors of N. Z., Ltd., as Assistant Engineer. A short time prior to his departure for New Zealand, Mr. Redwood was Works Engineer for the Canadian National Carbon & Prest-O-Lite Companies, Toronto, Canada.

H. G. Howard, of the Whitehall Securities Corporation, London, and Chief Engineer of the Cia Chilena de Electricidad, Santiago, Chile, has been appointed Hydroelectric Engineer to the Government of Madras, India. Major Howard was formerly Chief Engineer of the Mexican Light & Power Co., Mexico City.

Thomas F. Peterson, formerly Cable Engineer for the Brooklyn Edison Co., has recently resigned his position to become Cable Engineer in the Electrical & Wire Rope Sales Department of the American Steel & Wire Company, in which capacity he will serve as consultant to cable users on all problems appertaining to specifications, installations, jointing and testing of cables and wires.

Thomas Ahearn, pioneer in the field of electrical enterprise,—telegraphic, telephonic and power supply—is now one of those whose portraits hang on the walls of the Dominion Archives in a collection of outstanding Canadians. He is chairman of the Federal Improvement Commission and in this capacity has been doing vigorous construction work, as well as being the present president of the Ottawa Gas, Electric Light, Power & Traction Companies. Mr. Ahearn joined the Institute in 1887.

H. W. Brooks has resigned from the position of Consulting Engineer for the Erie City Iron Works, Erie, Pa., to reingage in a private consulting practise with offices in New York and St. Louis. He will, however, remain a resident of Fremont, Ohio. Mr. Brooks is internationally known for his research and development work in combustion and steam engineering and was formerly Fuel Engineer for the U. S. Bureau of Mines. During the War, he was Chief of the Machinery Section, Ordnance, U. S. Navy, and has served in both executive and advisory capacities in the design and construction of some of the largest power plants in North and South America. He is a member of the American Committee of the World Power Conference.

John Boswell Whitehead, Professor of Electrical Engineering and Dean of the School of Engineering at Johns Hopkins University, has recently returned from France, where, during the past academic year, he has been serving as Exchange Professor in Engineering and Applied Science. He visited the Universities of Aix-Marseille, Grenoble, Lyon, Bordeaux, Toulouse, Caen, Lille, Strasbourg, Nancy and Paris. In each of these universities he delivered a series of lectures on Dielectric Theory and Insulation. In Paris, lectures were delivered at the Sorbonne and at Ecole Superieure d'Electricite. The complete series of nine lectures are to be published by the Societe Francaise des Electriciens. In addition, Dr. Whitehead lectured before the Societe Francaise des Electriciens, and presented a paper on High-Voltage Insulation at the Conference Internationale des Grands Reseaux aux Hautes Tensions in Paris in June. In the various universities visited he made a special study of educational methods in the field of electrical engineering and conferred with many educators, scientists and engineers. He also visited many laboratories, manufacturing plants, and engineering installations. The University of Nancy conferred on Professor Whitehead its Medal of Honor.

## Obituary

**John L. Phillips,** Pacific Coast manager of the Okonite Company, died suddenly at San Francisco, September 6th, of heart failure. Mr. Phillips was well known in the electrical industries of the Pacific Coast. From 1900 to 1901 he was in the Electrical Department of the Northern Pacific Railroad, which position he left to become superintendent of the Electric Lighting Company at Staples, Minn. He returned to the Railroad Company the following year and remained with them as Signal Engineer until 1910. Then he became Assistant Engineer and Estimating Engineer for the General Railway Signal Company, Rochester, N. Y. In 1914, he was chosen Sales Engineer of the Central Railway Signal Company, New York, N. Y. and held this position up to the time of engaging with the Okonite company in 1919. Mr. Phillips joined the Institute in 1921.

**Sydney Fisher,** Production Engineer of the Bridgeport Brass Co. died October 16th, in Philadelphia. He was a native of Grays, Essex, England, but came to America at a sufficiently early age to receive his elementary education in the public schools of New York. He returned to England, however, for an electrical engineering course at the Woolwich Polytechnic Institute, Woolwich, Kent. This he took in conjunction with an apprentice course at Siemens Bros. & Co., Ltd., London. This was followed by a course at Columbia University, from which in 1914 he obtained his degree of Electrical Engineering. Prior to his last position as Production Engineer for the Bridgeport Brass Co., he engaged in general electric work for the Western Electric Co., New York, N. Y., the Westinghouse Electric & Mfg. Co., Pittsburgh, Pa. and was Electrical Engineer for the Remington Arms & Ammunition. Mr. Fisher joined the Institute in 1916.

**Roy D. Huxley,** Associate Professor of Electrical Engineering at the Case School of Applied Science, Cleveland, was killed September 2 in an automobile accident at Niagara Falls, N. Y. Professor Huxley was born Nov. 1889 at Florence, Massachusetts, and attended public school at Northampton. In 1907 he entered the Massachusetts Institute of Technology from which he graduated in 1911, receiving his degree of Master of Science in 1912 and of Doctor of Engineering in 1914. In 1912 he acted as Assistant in Civil Engineering at the M. I. T. Summer School and from September of that year to June 1914 was engaged in a post-graduate course there. During this time he designed and built an artificial transmission line for laboratory use. For a short time he was employed as engineering apprentice in the office of the Electrical Engineer, Boston Elevated Railway Company, planning and carrying out train-performance tests in the Cambridge Subway. From August 1914 for several years he was with the American Telephone and Telegraph Company in the Transmission and Protection Branch of the Engineering Department, dealing especially with problems of telegraph transmission and simultaneous telegraphy and telephony. Prof. Huxley became a member of the Institute in 1917.

## Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St. New York.

All members are urged to notify the Institute Headquarters promptly of any changes in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing

records, and the elimination of unnecessary expense for postage and clerical work.

Raymond W. Klotz, Cutler Hammer Mfg. Co. Milwaukee, Wis.
F. W. Molitor, General Delivery, Los Angeles, Calif.
Arthur B. Newell, 315 Marlborough Rd., Brooklyn, N. Y.
Richard T. Quass, 610 Cornell St., Perth Amboy, N. J.
Julius Ronay, Amer. Steel & Wire Co., Donora, Pa.
Martin S. Ruby, Lubbock, Tex.
Thomas Sheehan, 2126 Vyse Ave., New York, N. Y.
E. R. Shepard, 5522 Conn. Ave., Washington, D. C.
Richard A. Towers, 455 Lafayette Place, Culver City, Calif.
Sidney J. Wild, 869 Grand Ave., Oakland, Calif.
R. T. Wilkins, 158 Hicks St., Brooklyn, N. Y.
Benj. U. Young, Cheyenne Lt. Fuel & Pr. Co., Cheyenne, Wyo.

# Past Section Meetings

### Boston

Inspection trip to Fore River Yard of the Bethlehem Shipbuilding Corporation and the Airplane Carrier U. S. S. *Lexington.* Talk by Capt. L. Shane, U. S. N. October 1. Attendance 300.

### Cincinnati

*The Use of X-Ray, Medical and Commercial,* by W. S. Werner, Kelly-Koett Co. September 13. Attendance 126.

### Detroit-Ann Arbor

*The Value of Great Men,* by Dr. M. S. Rice. September 27. Attendance 92.

### Indianapolis-Lafayette

*Installation and Operation of the New Manual and Automatically Controlled Substations of Indianapolis Street Railway Company,* by L. C. Spencer. After the talk an inspection trip through two of the new substations, and demonstrations were made. September 23. Attendance 35.

### Los Angeles

*Tandem System of Handling Short-Haul Toll Calls in and about Los Angeles,* by F. O. Wheelock, Southern California Telephone Co. Illustrated. October 4. Attendance 101.

### Milwaukee

*The Progressive Development of Carbon-Dioxide Refrigeration,* by J. C. Goosman, Fred W. Wolf Company. September 21. Attendance 235.

### Minnesota

*A Motor Tour of Europe,* by Prof. G. W. Muhleman, Hamline University, and

*Latest Developments in Radio,* by C. M. Jansky, University of Minnesota. October 3. Attendance 18.

### New York

*Radio Broadcasting,* by Major J. Andrew White, President Columbia Broadcasting Co.;

*Radio Broadcasting as a Public Service,* by O. H. Caldwell, Federal Radio Commission and Supervisor of the New York District, and

*Commercial Aspects of Radio Broadcasting,* by Dr. A. J. Arnold, National Broadcasting Co. October 14. Attendance 125.

Radio Communications, by Senatore Guglielmo Marconi. This talk dealt with a review of Mr. Marconi's past and present work in beam radio projection, covering particularly measurements made with relation to fading, skip distances, paths followed by beams, effect of static, comparative values of various wavelengths, etc. October 17. Attendance 850.

### Niagara Frontier

*Carrier-Current Telephone,* by E. C. Markley, General Electric Co. September 23. Attendance 80.

### Philadelphia

*The Conowingo Project,* by N. E. Funk, Philadelphia Electric Co., and

*Electrical Features of the Conowingo Hydroelectric Plant,* by R. A. Hentz, Philadelphia Electric Co. Illustrated with slides. October 10. Attendance 300.

### Seattle

*General Problems Relating to High-Voltage Systems,* by R. D. Evans, Westinghouse Elec. & Mfg. Co. Illustrated. September 29. Attendance 74.

### Toronto

Social Meeting. September 30. Attendance 116.

*Recent Extensions in the Range of Telephonic Communication,* by Bancroft Gherardi, National President, A. I. E. E. September 17. Attendance 75.

### Vancouver

*Problems Relating to High-Tension Systems,* by R. D. Evans, Westinghouse Elec. & Mfg. Co. September 30. Attendance 38.

### Washington

*Vision by Radio,* by C. Francis Jenkins. Illustrated with motion pictures. October 11. Attendance 425.

# A. I. E. E. Student Activities

### STUDENT CONVENTION TO BE HELD IN CONNECTION WITH CHICAGO REGIONAL MEETING

Extensive plans for a Student Convention including both a technical program and a District Conference on Student Activities, to be held on the first day of the Regional Meeting of District No. 5, at Chicago on November 28-30, are being made by the District Committee on Student Activities in cooperation with the local committees.

Professor J. F. H. Douglas, Chairman of the District Committee on Student Activities, will preside.

#### TECHNICAL SESSION—9;15 A. M.

Monday, November 28

TENTATIVE PROGRAM

Address of Welcome, B. G. Jamieson, Vice-President, Great Lakes District.

*A-C. Rectifiers Where D-C. Component is Present,* J. P. Barton, University of Minnesota.

*A Study of Transverse Reaction in Synchronous Machines by the Use of a Synchronously Revolving Contactor,* E. Baldwin and E. Lashway, Marquette University.

*Errors in Current Transformers at Abnormal Loads,* L. L. Carter, Purdue University.

*Flux Distribution in D-C. Generator Teeth,* T. B. Holiday, Purdue University.

*Substation Protective Devices,* L. F. Masonik, Lewis Institute.

*Personal Experiences in the Location of Faults in Telephone Circuits,* Amerigo Sansone, Lewis Institute.

*History of the Development of A-C. Motors,* G. Conner, University of Notre Dame.

*Method of Securing the Compression Indicator Card of a High-Speed Compressor,* M. E. Fiene, University of Minnesota.

*History of the Development of D-C. Motors,* J. Horan, University of Notre Dame.

*Experience with Motor Maintenance in Paper Mills,* C. P. Feldhausen, University of Wisconsin.

*Cable-Fault Localization in Parkway Cable,* J. A. Sargent, University of Wisconsin.

*The Attitude of Student Engineers toward their Profession,* Student representing Rose Polytechnic Institute.

DISTRICT CONFERENCE ON STUDENT ACTIVITIES
2:00 P. M.

Report of Committee on Program—Professor C. M. Jansky, Chairman.

Symposium on Student Branch Problems From Student Point of View:

*The Management of Electrical Shows*, H. E. Hunt, Michigan State College.

*Financing of Branch Activities*, J. R. Adriansen, Marquette University.

*Branch Programs*, G. C. Brown, University of Minnesota.

*Ways and Means of Interesting Underclassmen in Branch Activities*, Arthur Dromp, Rose Polytechnic Institute.

*Social Activities of Branches*, L. J. Van Tuyl, University of Michigan.

General Discussion of Above Subjects.

*The Problem of the Branches*, Professor C. M. Jansky, Counselor, University of Wisconsin.

Discussion.

Unfinished Business.

Election of Officers of District Committee on Student Activities.

See page 1286 for complete information on other features of the Convention.

## BRANCH MEETINGS

### Municipal University of Akron

Business Meeting, after which those present attended the Akron Section meeting. Decided to hold meetings every three weeks. October 7. Attendance 12.

### Alabama Polytechnic Institute

*The Purpose of the Student Branch*, by Prof. W. W. Hill, Counselor. September 21. Attendance 50.

### Armour Institute of Technology

Business Meeting. October 7. Attendance 31.

### California Institute of Technology

*Account of the Pacific Coast Convention*, by J. W. Thatcher. October 5. Attendance 12.

### University of California

*Efficiency*, by Dean Woods, and

*Looking Ahead*, by Mr. Winters. Banquet and Initiation. Other short talks were given by Dean Cory, Prof. Balsbaugh, Prof. McFarland and A. G. Montin. September 29. Attendance 101.

### Clarkson College of Technology

Business Meeting. The following officers were elected: Chairman, G. L. Rogers; Treasurer, D. L. Mayne; Secretary, J. Schuyler Loomis. October 1. Attendance 45.

### Colorado Agricultural College

Business Meeting. September 26. Attendance 20.

### University of Colorado

*The Benefits of Belonging to the A. I. E. E.*, by A. L. Jones, Chairman, Dean H. S. Evans, and Professor W. C. DuVall, Counselor. The following motion pictures were shown: "The Electrical Giant" and "The Transatlantic Telephone." H. R. Arnold was elected Secretary. September 28. Attendance 70.

*Problems in Telephone Transmission*, by W. G. Rubel, President, Mountain States Telephone Co. October 5. Attendance 60.

### Drexel Institute

Business Meeting. Discussion of program for the year. Talks were given by Professors R. C. Disque, Dean, and E. O. Lange, Counselor. September 30. Attendance 18.

### University of Idaho

*Review of the Lake Chelan*, Washington Hydroelectric Project of the Washington Water Power Company, by C. L. Farrar. A short lecture on "Purposes and Principles of Student Branches of the Institute" was also given by Prof. J. H. Johnson. October 6. Attendance 26.

### Iowa State College

Business Meeting. General discussion of year's activities. The following officers were elected: President, Wm. H. Curvin; Secretary, W. H. Stark. May 31. Attendance 15.

### State University of Iowa

Business Meeting. The following officers were elected: Chairman, F. L. Kline; Vice-Chairman, J. T. Jones; Secretary, M. B. Hurd. September 28. Attendance 23.

*Electrification of Gold Mines*, by J. S. Beck, and

*Light from Heat*, by N. R. Bector. October 5. Attendance 23.

### University of Kansas

*The Purposes of the A. I. E. E. and the Advantages of Membership In It*, by Professor G. C. Shaad, Counselor. October 6. Attendance 90.

### Lafayette College

Business Meeting. The following officers were elected: Chairman, John W. Dagon; Secretary, H. W. Loveth. October 1. Attendance 22.

### Lewis Institute

Business Meeting. October 4. Attendance 21.

### Michigan State College

A motion picture entitled "Wizardy of Wireless," was shown October 4. Attendance 54.

### Mississippi A. & M. College

Business Meeting. Short talks were given by Professor L. L. Patterson, Counselor, and Prof. Commander. R. S. Kersh was elected Secretary-Treasurer. October 6. Attendance 45.

### University of Missouri

*Aims and Activities of the A. I. E. E.—Why Electrical Students Should Be Enrolled*, by Prof. M. P. Weinbach. October 3. Attendance 35.

### University of Nebraska

*Electrification of Railways*, by J. M. Zimmerman, Westinghouse Elec. & Mfg. Co. Illustrated with slides and motion pictures. September 29. Attendance 125.

### University of Nevada

Business Meeting. September 7. Attendance 45.

### Newark College of Engineering

*My Impressions of the General Electric Company at Schenectady This Summer*, by Prof. J. C. Peet, Counselor. H. L. Harrison was elected Secretary. October 6. Attendance 39.

### University of New Hamsphire

Talk by Chairman S. S. Appleton on the Pittsfield Regional Meeting. September 21. Attendance 39.

*Spot Welding of Dissimilar Metals*, by G. P. Balch;

*High Pressure Steam—Its Advantages and Disadvantages*, by F. E. Beede, and

*Street Lighting Control Systems*, by S. S. Appleton. September 28. Attendance 39.

A section of Park's "English Applied to Technical Writing" was discussed by L. E. Boodey, F. W. Drew and I. Gove. October 5. Attendance 39.

### College of the City of New York

Inspection trip through the Schenectady Works of the General Electric Co. September 19 and 20. Attendance 9.

Motion picture, entitled "The Busybody" was shown. A tentative program for the term was presented. September 29. Attendance 32.

### North Carolina State College

Business Meeting. September 26. Attendance 8.

Get-together Meeting. Short talks were given by Professor Wm. H. Browne, and C. W. Ricker and Chairman J. C. Davis. October 3. Attendance 83.

### University of North Carolina

Short talks were given by Professors Dagget, Lear, and Smiley, and Chairman D. M. Holshouser. September 29. Attendance 35.

**Northeastern University**

*Insulated Wire and Cable*, by E. W. Davis, Simplex Wire & Cable Co. The Branch voted that a $5.00 prize should be given to the student presenting the best paper before it. September 27. Attendance 55.

**Ohio State University**

Freshman Party. After the exhibition of laboratory apparatus and the University Broadcasting Station, welcome addresses were given by the Chairman, A. B. Crawford, and Professor F. C. Caldwell, Counselor. September 26. Attendance 55.

Business Meeting. October 7. Attendance 30.

**Oklahoma A. & M. College**

Motion picture, entitled "Fifty Years of Telephone Progress," was shown. October 5. Attendance 30.

**University of Oklahoma**

*The Qualifications of a Good Engineer*, by Milton Dewitt;

*The Michigan Institute of Technology*, by Prof. Walters, and

*The Membership of the A. I. E. E. and the* JOURNAL, by Prof. F. G. Tappan, Counselor. October 6. Attendance 27.

**Pennsylvania State College**

Social Meeting. September 28. Attendance 145.

Talks on their summer work were given by four students—J. L. Wagner, C. F. Bryant, L. Hane, and W. J. Gorman. The following officers were elected: Vice-President, J. F. Houldin; Assistant Secretary, R. L. Hallett. October 12. Attendance 37.

**Purdue University**

Organization Meeting. Talks on A. I. E. E. by Professors Harding, Topping and Rowell. October 4. Attendance 116.

**Rhode Island State College**

*The Purpose and Privileges of the A. I. E. E.*, by Prof. Wm. Anderson, Counselor. September 30. Attendance 21.

*Electronic Rectifiers*, by Prof. Wm. Anderson. October 7. Attendance 33.

**Rose Polytechnic Institute**

Business Meeting. September 23. Attendance 25.

**University of South Dakota**

*The Advantages of Student Enrolment in the A. I. E. E.*, by Dr. B. B. Brackett, Counselor. Talks on the International Units were also given by Dr. Brackett and Stanley Boegler, Chairman. September 28. Attendance 13.

**Texas A. & M. College**

Business Meeting. The following officers were elected: Chairman, J. L. Pratt; Secretary, H. W. Whitney. September 30. Attendance 85.

**Virginia Military Institute**

*The A. I. E. E., Its Purpose, Membership and History at V. M. I.*, by Col. S. W. Anderson;

*Educational Advantages of the A. I. E. E.*, by Maj. R. J. Trinkle;

*Graduate Courses in Different Industries*, by Capt. J. S. Jamison, and

*Programs and Plans for the Coming Year*, by D. N. Higgins, R. D. Ketner and G. H. Shield. September 22. Attendance 28.

**University of Virginia**

*An Electrical Engine Starting System for Automobiles*, by C. H. Davis, Jr., Secretary. A motion picture, entitled "Revelations by X-Ray," was shown. October 6. Attendance 25.

**Washington University**

Business Meeting. October 6. Attendance 39.

**University of Washington**

A talk was given by Dean C. E. Magnusson on the A. I. E. E. and on the Conference on Student Activities held at Detroit in June. October 7. Attendance 35.

**West Virginia University**

Business Meeting. The following officers were elected: President, G. B. Pyles; Vice-President, G. E. Phillips; Secretary, C. C. Coulter; Treasurer, C. M. Borror; Publicity Manager, S. C. Hill. September 26. Attendance 34.

**University of Wyoming**

Business Meeting. The following officers were elected: President, James O. Yates; Vice-President, Stephen Anderson; Secretary-Treasurer, Ervin C. Moudy. Means of getting new members and making a success of the organization were discussed. October 11. Attendance 7.

# Engineering Societies Library

*The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is adminstered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.*

*In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made*

*The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.*

*The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.*

*The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m*

## BOOK NOTICES, SEPT. 1-30, 1927

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

AIRPLANE DESIGN; Aerodynamics.

By Edward P. Warner. N. Y., McGraw-Hill Book Co., 1927. 598 pp., diagrs., 9 x 6 in., cloth. $7.50.

Professor Warner has endeavored to provide a textbook for the student interested in the practical application of aerodynamic theories to design. He has tried to systematize, correlate and coordinate the results of the great mass of experimental data which has been accumulated, and to present the results in a way which can be understood by a student of moderate mathematical attainments. The book is based upon extensive experience as a designer and teacher.

DREHSTROM-INDUKTIONSREGLER.

By H. F. Schait. Berlin, Julius Springer, 1927. 356 pp., illus., diagrs., 9 x 6 in., boards. 25,50 r. m.

A treatise on the design, construction and operation of polyphase induction regulators. The first chapter treats analytically the design of these regulators, while in the second chapter

the same material is handled vectorially; the combination giving a foundation for practical design. Heating and cooling are then treated with the fullness that their importance warrants. The methods advocated are then illustrated by an example. The final chapter is intended for the operator, rather than the designer, and discusses construction and operation.

Electric Elevators.

By F. A. Annett. N. Y., McGraw-Hill Book Co., 1927. 447 pp., illus., diagrs., 9 x 6 in., cloth. $5.00.

This is a welcome addition to the scanty literature on modern elevators. It is descriptive rather than theoretical, and while all types of electric elevators are included, the emphasis is placed upon the latest designs. The book will be useful to those who select and operate elevators.

Electric Power Equipment.

By J. G. Tarboux. N. Y., McGraw-Hill, 1927. 455 pp., illus., diagrs., tables, 9 x 6 in., cloth. $5.00.

A book of broad scope, intended to give a bird's-eye view of the whole field of electrical power equipment to students who already understand the fundamentals of electrical circuits and machinery.

Starting with a brief survey of power resources, a study of types of prime movers and a discussion of loads and load graphs, the topics treated include generating equipment, synchronous generator excitation, circuit layouts, switching equipment, meters, transformers, switchboards, short-circuit currents, current-limiting reactors, transmission lines, distribution systems, etc. The book aims to present the essential elements of these subjects, so that the student will acquire a general understanding of them.

Lehrgang der Härtetechnik.

By Joh. Schiefer and E. Grün. 3rd edition. Berlin, Julius Springer, 1927. 211 pp., illus., diagrs., tables, 9 x 6 in., paper. 7,50 r. m.

A practical textbook on hardening and tempering for toolmakers. The book first explains the physical and chemical properties of steel, the methods of manufacture and the common physical tests. The arrangement and equipment of tempering shops are then described, after which the tempering and hardening of tools for various purposes are discussed in detail.

Personnel.

By George R. Hulverson. N. Y., Ronald Press Co., 1927. (Business administration series). 400 pp., forms, 9 x 6 in., cloth. $4.50.

Discusses methods of developing and directing the staff of large business organizations through a personnel department. The technique and objectives of this department are treated in detail, but the problem of its general administrative control is emphasized. The author has tried to summarize the principal features and the limitations of various methods in such a way as to assist the executive in selecting the best plans for his own needs.

Purchasing.

By W. N. Mitchell. N. Y., Ronald Press Co., 1927. (Business administration series). 385 pp., forms, 9 x 6 in., cloth. $4.50.

A study of the purchasing function in business organizations. Basic policies are compared, methods of coordinating the work of the purchasing department with other departments are discussed and the relations of purchasing to the business as a whole are clearly brought forward. The treatment is general, based on the kind of commodities bought and the purposes in buying them, irrespective of routine details for a particular business.

Pyrometry.

By William P. Wood and James M. Cork. McGraw-Hill Bk. Co., 1927. 207 pp., illus., diagrs., 9 x 6 in., cloth. $3.00.

Intended as a textbook for college students, rather than for use as a reference work. Describes the various types of instruments for measuring, recording, controlling temperatures, and discusses transition points and thermal analysis. Problems and outlines for laboratory work are included.

See-Und Hafenbau.

By Franz Franzins and Karl Bökemann. Ber. u. Lpz., Walter de Gruyter & Co., 1927. 152 pp., illus., 6 x 4 in., cloth. 1,50 r. m.

An attempt to present this broad topic in the most concise and still easily understandable form. The little book discusses the sea and its movements, coast forms, the protection of land from encroachment and the construction of harbors, docks, etc.

Theory and Practise of Rolling of Steel.

By Wilhelm Tafel. Translated by Richard Rimbach. Cleveland, Penton Publ. Co., 1927. 300 pp., diagrs., tables, 9 x 6 in., cloth. $6.00.

A welcome addition to the scanty literature of rolling. The work is an introduction to the theory and understanding of rolling and roll-pass design, and the author endeavors to present the reasoning which is necessary for successful design, rather than a collection of solutions of specific problems. The theories and technical conceptions of rolling are discussed. The design of passes and the arrangement of rolls are studied and the design of passes for merchant bars and shapes requiring equal and unequal draft is discussed in detail. A chapter is devoted to power requirements of roll trains and methods of driving.

Untersuchung von Schneckentrieben.

By Rudolf Gruson. Mün. u. Ber., R. Oldenbourg, 1927. (Berlin Technische Hochschule. Versuchsfeld für Maschinenelemente. Heft 7). 27 pp., diagrs., tables, 11 x 8 in., paper. 4,-r. m.

Describes tests of a worm gear. A formula for temperature was found and the points of greatest efficiency and the admissable load were determined. The properties of the most suitable oil and the narrowest possible breadth of wheel were ascertained.

Versuche mit Fangvorrichtungen an Aufzugen.

By Gerold Weber. Mün. u. Ber., R. Oldenbourg, 1923. (Berlin Technische Hochschule. Versuchsfeld für Maschinenelemente, Heft 5). 40 pp., illus., diagrs., 11 x 8 in., paper. 3,20 r. m.

Gives in detail the results of a series of tests of safety brakes for elevators. Four types of brakes were tested, the experiments being made at the testing field of the Berlin Technical High School.

Automotive Giants of America.

By B. C. Forbes and O. D. Foster. N. Y., B. C. Forbes Publishing Co., 1926. 295 pp., ports., 8 x 5 in., cloth. $2.50.

Brief biographies of twenty leaders in the automobile industry, originally published in "Forbes Magazine."

Shipbuilding and the Shipbuilding Industry.

By J. Mitchell. N. Y., Isaac Pitman & Sons, [1926]. (Pitman's Common Commodities and Industries). 116 pp., illus., charts, 7 x 5 in., cloth. $1.00.

This little book gives an excellent account of the way in which a ship is designed and built, written so that an inexperienced reader can understand it. Attention is paid to the problems of material and labor, as well as the problems of engineering, involved in making a ship, and the book should interest many who are curious about these matters.

Casein and its Industrial Applications.

By Edwin Sutermeister. N. Y., Chemical Catalog Co., 1927. (American Chemical Society, Monograph series). 296 pp., illus., diagrs., tables, 9 x 6 in., cloth. $5.00.

This monograph brings together, in readable form, our knowledge of casein, of its manufacture and of its uses in paints, paper making, plastics, glues, medicines, foods, etc. There are also chapters on storage and analysis, and numerous bibliographic references are given throughout.

# Engineering Societies Employment Service

*Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.*

*Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.*
*53 West Jackson Blvd., Room 1736, Chicago, Ill., A. K. Krauser, Manager.*
*57 Post St., San Francisco, Calif., N. D. Cook, Manager.*

*MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to* ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th day of the month.*

*OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.*

*VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above will it is hoped, be sufficient not only to maintain, but to increase and extend the service.*

*REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.*

### POSITIONS OPEN

DRAFTSMAN. Large manufacturing concern in New York, metropolitan area, has opening for electrical, mechanical and architectural draftsmen. Location, New Jersey. X-3482.

ELECTRICAL AND MECHANICAL ENGINEER, preferably graduate, under 40, experienced in design and manufacture of switches, fuses, panel boards, receptacles and similar electrical accessories, as general assistant to chief engineer of concern producing such devices. Should be willing and able to work at the board and handle small as well as big jobs. Opportunities. Apply by letter. Location, East. X-628.

### MEN AVAILABLE

ELECTRICAL, INDUSTRIAL, AND TELEPHONE ENGINEER has knowledge of cost accounting, production engineering, and telephone engineering as applied to inductive coordination. Has had wide experience in investigations, special studies, reports, etc. High grade mathematical talent. Desires position where he can be of productive service. Available at once. B-5572.

ESTIMATING, ACCOUNTING, APPRAISAL ENGINEER, A. I. E. E., 26, married. Two years construction work, one year valuation work, Westinghouse graduate course. Well trained in public utility economics and estimating. Prefer engineering economic work in connection with public utility expansion or railway electrification. C-3082-1331.

ELECTRICAL ENGINEER, 22, recent graduate, desires position in installation or maintenance department. Available at once. Location, New York State. C-3582.

MECHANICAL AND ELECTRICAL ENGINEER, 34, married, no children, 15 years' varied experience in factory management, plant design, construction and maintenance, telegraph (cable and wireless), and telephone design and layouts. Desires change where head and hands are required. Location, anywhere. European and Oriental experience. C-2151.

ELECTRICAL ENGINEERING GRADUATE with three years' practical experience available for technical work to be performed at home. Calculation and tracing a specialty. Location, New York City. C-3593.

PUBLIC UTILITY EXECUTIVE, 47, technical graduate, 25 years' experience in all kinds of public utility work. Ten years' experience in construction, engineering and operation of steam and hydroelectric systems, including generation, transmission and distribution. Fifteen years' experience in executive capacity, covering appraisal, rate structures and adjustments, public service commission controversies, new business building, public relations, power sales, intensive new business campaigns. Experienced in the management of electric, artificial gas and steam heating. Now engaged in winding up affairs of large public utility. C-3394.

ELECTRICAL ENGINEER, A. I. E. E., 37, single, desires position with engineering concern or public utility. Sixteen years' engineering and construction experience in the design of power and substation power and lighting of industrial buildings. Location desired, East. C-2011.

ASSISTANT TO EXECUTIVE. Executive experience, scientific mind, engineering knowledge offered executive who demands exceptional ability and exact results. Training: M. I. T. 5 years in chemistry, mathematical physics, mechanical engineering. Experience: reports, technical writing; design; shop, scientific; industrial and financial research; systematizing; estimates and costs on equipment, buildings, labor. Economist. B-9930.

ELECTRICAL ENGINEER, office and field experience, familiar with operation, construction and design, public utility, steam and hydroelectric generating stations, substations, transmission line calculations, laboratory, field and factory testing. Industrial power applications and maintenance in plants and buildings. Have been resident and office engineer—engineering firm. In charge engineering office public utility. C-3587.

ENGINEER EXECUTIVE, 36, married, E-E-1914. 12 years' diversified experience on distribution, installation, and sales. Past seven years assistant to head of sales department, handling reports, publicity, stock, purchasing. Desires position where iniative, ability, and hard work will be recognized. Either as executive, or assistant who is required to get things done. Interested in manufacturing or public utility field. Location, Middle West. C-3616.

GRADUATE ELECTRICAL ENGINEER, single, 24, seven months design and installation supervision, electrical equipment for large structural company, also twenty-one months on General Electric test and a year's construction experience on hoisting equipment. Wishes to be connected with some industrial or utility company in East or Middle West. Available October. C-3538.

PLANT ENGINEER, 33, married, fourteen years' experience both electrical and mechanical in all phases of maintenance, construction and operation, nine years of which were in responsible charge of work, in industrial plants such as small parts manufacture, textile and cotton mills, zinc spelters and steel industries. Location preferred, Eastern U. S. B-5026.

MARINE ELECTRICIAN, graduate, four years course electrical school, 39, married. 15 years' experience as inspector and chief electrician on shipboard and yards. Graduate of Sperry-Gyro compass school. Willing to travel, available on short notice. C-3634.

POSITION OF A STRICTLY TECHNICAL NATURE desired by graduate electrical engineer. Five years' experience, employed. Industrious and adaptable. B-9775.

GRADUATE ENGINEER, 18 years' experience with contracting and engineering companies, both sales and as executive in charge of office and the design and installation of mechanical equipment of industrial plants, power plants, etc. Capable taking complete charge engineering or contracting office or as sales representative. Location, New York City. B-5050.

TECHNICAL GRADUATE, 25, married, experienced in single-phase and polyphase meter test. Also some experience in steel mill electrical construction, maintenance and general testing. Location, immaterial. B-7464.

ELECTRICAL ENGINEER, 26, 3 years' experience in radio research, development and service work. Speaks Spanish fluently. Research or sales work preferred. C-648.

ELECTRICAL ENGINEER, 40, married, desires to locate with engineering firm of public utility, 18 years' experience covering office and field, familiar with electrical and mechanical design and construction, of public utility steam and hydroelectric generating station, substation and general engineering. B-7779.

ENGINEER, technical graduate, 28, married, six years' experience in construction work estimating, bidding, purchasing, field work and general supervision of water works pumping stations, filter plants, power plants, substations and transmission lines. Desires connection with large general contracting firm or industrial organization. Location U. S. or Cuba. B-7699.

YOUNG MAN, 29, electrical engineering degree, instructor in mathematics and physics for past four years wishes to break in on some line of work compatible with experience and with promise

of a future. Has Master's degree in physics and about two years' experience on motors and radio. Initial salary immaterial. B-3411.

ELECTRICAL ENGINEER, 26, married. 1922 graduate. Successful experience power station design and propositions: steam turbines and Diesel engines. Three years South America: Mine electric shovels (Bucyrus and Marion), mine and mill equipments. Wishes premanent responsible position anywhere, where practical experience is helpful. Ask for highest reference and credentials of fulfilled duties. Available immediately. C-2084.

CONSTRUCTION MANAGER, graduate, 15 years' public utility experience, open for connection as construction manager, chief engineer, operating executive for operating company. Now in charge three and a half million dollar high-tension transmission line and substation project, nearing completion. Available about February, 1928. Can bring complete, experienced organization, financial, clerical, technical, to handle construction force of 500 men on power plant, transmission line and substation construction. A-2191.

RADIO ENGINEER, B. S. in E. E., with five years' diversified radio experience in responsible position with large manufacturing corporation in East with whom he is now employed. Desires position in West or Southwest as radio engineer for reliable manufacturing concern or as communication engineer for large power system. C-3654.

FOREIGN DEPARTMENT MANAGER OR ASSISTANT MANAGER, 44, electrical engineer, graduate of large eastern University, Memb. Soc. C. E., A. I. E. E., will take charge of foreign sales and contract relations. Speaks fluently and writes correctly English, French, German, Spanish and Italian, and has personal contacts in many foreign countries. Able to organize Foreign Department. Available on thirty days' notice. C-3655.

SALES ENGINEER, with several years' electrical sales experience in New York territory, desires connection in same territory on salary or preferably commission basis. Degree from leading university also Westinghouse course. B-9863.

COMMERCIAL ENGINEER, 24, single, technical graduate, industrial electrical engineering, two years public utility work in commercial, engineering, statistical and rate work. Desires permanent connection with public utility or industrial firm; preference commercial work developing into sales. Willing to travel, available on two weeks' notice. C-1910.

ELECTRICAL DESIGNING ENGINEER, graduate in E. E. in 1918 from well known university; 10 years' experience in the design of hydroelectric and steam central station, indoor and outdoor substations. Capable organizer of drafting room work with high grade drafting ability. C-3657.

YOUNG MAN, 29, associate member of the A. I. E. E., 3 years electrical tests, four years teaching electrical theory. Desires position in an engineering office preferably in the East. Available on one month's notice. C-3658.

ELECTRICAL ENGINEER, B. S. in E. E. 1924, age 25. Three years' public utility experience, involving estimating, testing, and studies directed along industrial lines. Desires connection with manufacturing or consulting firms. Location preferably New York City or vicinity. B-8400.

ELECTRICAL AND MECHANICAL ENGINEER, 15 years' experience, married, age 31, desires position as superintendent of construction or maintenance engineer, 4 years general and electrical superintendent in large electrochemical plant. Location, immaterial. Available at once. C-3671.

ELECTRICAL ENGINEER, 28, single, graduate electrical engineer, 2 years General Electric test department, 1 year requisition and complaint work. Two years contract and sales on lighting fixtures and radios. Available on short notice. Location, anywhere. B-9090.

GRADUATE ELECTRICAL ENGINEER AND RADIO MAN, single, age 21, desires position with some reputable concern. Experienced in motor test, soliciting, general construction and drafting work. Familiar with French, Spanish and English languages. References can be furnished. Location, immaterial. Available on notice. C-3678.

ENGINEER, EXECUTIVE, MANAGER, graduate E. E., 14 years' experience including wide experience in accounting, design, sales, production, electrical porcelain, management of large plant for national corporation. Broad knowledge of engineering materials. Loyalty, initiative and record of assuming responsibility is unquestioned. Interested in business and management of electrical specialty. Can organize, manage operations efficiently and economically. Married. C-3679.

SALES ENGINEER, technical graduate with twelve years' experience in developing, manufacturing and selling mechanical and electrical equipment for steam and electric railways. Has specialized in the design, installation and sale of power saving, lubricating and draft appliances. Capable, industrious with pleasing personality. Available immediately. B-6873.

ELECTRICAL ENGINEER, 27, single, graduate, 6 years' experience (2 in responsible position) in selection installation, operation and maintenance electrical equipment on industrial plants, familiar with power plant equipment, railroad work included, steam and electric (A. C. and D. C.). Desires position along these lines. Location preferred, New York or New England. C-3467.

PLANT ENGINEER, 38, single. Technical graduate in electrical engineering, employed during the past eight years as electrical engineer and assistant plant engineer in charge of maintenance in large industrial plant. Location preferred, U. S. A. C-2660.

CHIEF ELECTRICAL DRAFTSMAN, 26' married. A man with technical education and a large field of experience on design and construction work on high or low tension substations. Capable of handling men. Desires steady position on engineering staff of public utility. Field work preferred. Location preferred, New York, Pennsylvania, Ohio or New England States. C-3123.

ELECTRICAL ENGINEER, 37, married, ten years' experience, public utilities, specializing sales engineering, power sales, managing new business departments. Also experienced as electrical manufacturer representative in New York territory, selling motors, transformers, electric vehicle batteries. Desires position New York territory as electrical manufacturer's representative or public utility sales engineer. A-796.

ELECTRICAL, MECHANICAL SUPERINTENDENT, age 44, married, 25 years' experience in the installation and maintenance of electrical equipment of public utility power plants and substations, and the electrical and mechanical equipment of industrial and Diesel-electric marine plants. Details on request. Available on reasonable notice. B-721.

TECHNICAL GRADUATE, Fellow A. I. E. E., Member A. S. M. E., age 37; 15 years' experience in design, construction and operation of electric utilities, including generation, transmission and distribution. Have also actively engaged in power sales and public relations. Desire permanent position with opportunity for advancement. B-6794.

# MEMBERSHIP — Applications, Elections, Transfers, Etc.

### ASSOCIATES ELECTED OCTOBER 19, 1927

ABRAHAM, GEORGE P., Detailing & Designing Engg. Dept., Philadelphia Electric Co., 2301 Market St., Philadelphia, Pa.

ALDERMAN, HAYWOOD LEWIS, Assistant Engineer, Electric Bond & Share Co., 2 Rector St., New York, N. Y.

ARMOUR, WESLEY, Foreman, Meter Dept., Windsor Hydro-Electric System, 796 McDougall St., Windsor, Ont., Can.

BARNHART, CHARLES, Chief Electrical Engineer, Cooper Corp., Findlay, Ohio.

BLOWES, WALTER JOHN, Sub-Foreman, Electric Constr. Dept., E. L. Phillips & Co., Far Rockaway, N. Y.

BROWN, HARLEY E., Assistant Signalman, Pennsylvania Railroad, 440 S. McKinley Ave., Newcomerstown, Ohio.

BROWN, HART, Electrical Engineer, Southwestern Oil Co., 1201 Union National Bank Bldg., Houston, Texas.

COURT, WILLIAM EDWARD, Operator, Lake Buntzen Power Plant, Vancouver Power Co., Lake Buntzen, Burrard Inlet, B. C., Can.

DERENKOWSKY, PINCHUS, 904 Tiffany St., New York, N. Y.

DOOBIN, ABRAHAM M., Engineering Apprentice, Harmon Electric Shop, New York Central Railroad, 466 Lexington Ave., New York, N. Y.

DOWNER, JASON B., City of Seattle Water Dept., Seattle, Wash.

GARROWAY, D. C., Salesman, Locke Insulator Corp.; General Electric Co., 1301 Pierce Bldg., St. Louis, Mo.

GODOY, ERNESTO RUIZ, Toll Wire Chief, Mexican Tel. & Tel. Co., Ezeqiel Montes No. 12, Mexico, D. F., Mex.

GOODMAN, ISADORE E., Proprietor, Goodman Engineering Co., 9612 Thorn Ave., Cleveland, Ohio.

HEAP, JOHN GRAVES, Mining Service Engineer, General Electric Co., 112 N. 4th St., St. Louis, Mo.

HILTON, ERNEST JAMES, Switchboard Wireman, Scranton Electric Co, Scranton; res., Dalton, Pa.

HOLLISTER, JOHN W. A., Groundman, Trinidad Electric Trans., Ry. & Gas Co., Trinidad; res., Walsenburg, Colo.

HOOPER, DOUGLAS B., Chief Electrician, Canadian Pacific Railway, Chateau Lake Louise, Alberta, Can.

JEFFERSON, HARRY D., Electrical Engineer, Matson Navigation Co., S. S. Malolo, San Francisco, Calif.; for mail, Gibbs Bros., 1 Broadway, New York, N. Y.

JOHNSON, OSCAR EDWARD, Telephone Maintenance, Puget Sound Power & Light Co., 2216 16th Ave. So., Seattle, Wash.

KELLEY, FRANCIS E., Engineer, Products Protection Corp., Box 904, New Haven, Conn.

KENNEDY, JOHN T., Engineer, Cutler-Hammer Mfg. Co., 12th St. & St. Paul Ave., Milwaukee, Wis.

KNAPE, CHARLES HUGO M., Checker, Westinghouse Elec. & Mfg. Co., Homewood Works, Pittsburgh; res., East Pittsburgh, Pa.

McLELLAN, ANDREW ROY, Research Work, Vesta Battery Corp., 6405 Dorchester Ave., Chicago, Ill.

McWHA, ROBERT DUPREE, Electrical Engineer, General Electric Co., Pierce Bldg., St. Louis, Mo.

MOHRI, KEIZOH, Engineer, Okazaki Dento K. K., Okazaki, Aichiken, Japan.

MONTAPERT, ALFRED ARMAND, Supervising Electrician, Safety Elevator Corp., 2127 S. Los Angeles St., Los Angeles, Calif.

MURATA, YATSUKA, Electrical Engineer, Nippon Gaishi Kabushiki Kaisha, Atsuta-higashimachi, Nagoya City, Japan.

NAUGLE, JOHN BARCLAY, District Sales Manager, Ohio Brass Co., 532 Matson Bldg., San Francisco, Calif.

NOBLE, HORATIO JAMES G, Meters Engineering Assistant, Electricity Dept., Shanghai Municipal Council, Shanghai, China.

OTT, ALBERT, Electrical Engineer, American Brown Boveri Electric Corp., Camden; res., Collingswood, N. J.

PARKIS, DONALD MEIER, Manufacturing Analyst, Western Electric Co., Hawthorne Works, Chicago, Ill.

REICHARD, HERBERT HERSH, Research Assistant, Harvard Engineering School, Harvard University, 205 Pierce Hall, Cambridge, Mass.

RITTMAYER, BENJAMIN FRANKLIN, Electrical Draughtsman, Simon & Simon, 249 S. Juniper St., Philadelphia, Pa.; res., Camden, N. J.

SCHALCHER, OTTO, American Brown Boveri Electric Corp., Camden, N. J.

SKAAR, JOHN, Power Station Operator, Illinois Steel Co., South Chicago; res., Chicago, Ill.

STRATTON, SYLVERN EUGENE, Electrician, Atlantic City Electric Co,, Atlantic City, N. J.

TABLER, LEE D., Instructor, Electrical Engineering Dept., Georgia School of Technology, Atlanta, Ga.

THOMPSON, CHARLES LEONARD L., Superintendent, Fire & Police Alarm Systems, City of Tacoma, 832 A St., Tacoma, Wash.

TOWNSEND, WILLIAM WAVERLY, Warrant Electrician, United States Navy, Navy Dept., Washington, D. C.; for mail, San Francisco, Calif.

TUTTON, PHILIP AUBREY, Assistant Superintendent, Transformer Division, Riegos y Fuerza del Ebro, S. A., Plaza de Cataluna 2, Barcelona, Spain.

VON EIFF, HERMAN ALBERT, Efficiency Engineer, Penn. Water & Power Co., 1611 Lexington Bldg., Baltimore, Md.

WARWICK, GEORGE GUY, Supt. of Power Houses, Vancouver Power Co., Burrard Inlet Floating P. O., Lake Buntzen, B. C., Can.

*WILLIAMS, ROY MARSHALL, Representative, West Virginia Engineering Co., Norton, Va.

Total 44.

*Formerly enrolled students.

**ASSOCIATES REELECTED OCTOBER 19, 1927**

LEAVITT, HENRY JOSEPH, Teacher of Electricity, Albany Part-time School, Albany, N. Y.

VIETS, FLOYD HARVEY, Chief Engineer, Western Precipitation Co., 1016 W. 9th St., Los Angeles; for mail, Glendale, Calif.

**TRANSFERRED TO GRADE OF MEMBER OCTOBER 19, 1927**

BODEN, WALTER A. Sales Engineer, Ward Leonard Electric Co., Mt. Vernon, N. Y.

BROWN, FREDERIC S., Assistant Electrical Engineer, Byllesby Engg. & Mgt. Corp., Pittsburgh, Pa.

BUGBEE, RALPH L., Electrical Designer, Stone & Webster, Inc., Boston, Mass.

CALL, LLOYD L., Chief Engineer, Victor X-Ray Corp., Chicago, Ill.

CANARIIS, SVEND A., Senior Engineer, Duquesne Light Co., Pittsburgh, Pa.

CONKLING, DeWITT C., Electrical Machinist, The Panama Canal, Balboa, Canal Zone.

DAVIS, WILLIAM S., Meter and Wiring Engineer, Public Service Electric & Gas Company, Newark, N. J.

ELDREDGE, WILLIAM S., Testing Engineer in charge of Generating Stations, Commonwealth Edison Co., Chicago, Ill.

ELLIOTT, EDWARD B., Engineer, Stone & Webster, Inc., Boston, Mass.

FARON, FRANK A., Electrical Engineer, Railway Engg. Dept., General Electric Co., Schenectady, N. Y.

FLEMISTER, S. A., Transmission and Protection Engineer, Southern Bell Tel. & Tel. Co., Atlanta, Ga.

GEORGE, ROBERT B., Electrical Engineer, Westinghouse Elec. & Mfg. Co., Sharon, Pa.

GOODALE, J. ELMER, Assistant Electrical Engineer, N. Y. & Queens Elec. Lt. & Pr. Co., Flushing, N. Y.

GOODMAN, LYNN S., Assistant Supt., Statistical Bureau, Edison Electric Illuminating Co. of Boston, Boston, Mass.

HERBST, WILLIAM B., Assistant Electrical Engineer, Dept. of City Transit, Philadelphia, Pa.

HIGGINS, D. D., Electrical Assistant to Supt., of Generating Stations. Commonwealth Edison Co., Chicago, Ill.

HOLBEN, WILMER P., Distribution Design-Section Engineer, Byllesby Engg. & Mgt. Corp., Pittsburgh, Pa.

KYLE, GEORGE L., Electrical Engineer, U S L Battery Corp., Niagara Falls, N. Y.

LANGSTAFF, HAROLD A. P., Relay Engineer, West Penn Power Co., Pittsburgh, Pa.

LANSIL, CLIFFORD E., Assistant Prof. of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

LAURENCOT, HENRY J., Assistant System Engineer, Brooklyn Edison Co., Brooklyn, N. Y.

LEUREY, LOUIS F., Consulting Electrical Engineer, 58 Sutter St., San Francisco, Calif.

LOSHING, CLEMENT K., Electrical Engineer, Cleveland Electrical Illuminating Co., Cleveland, Ohio.

LUICHINGER, MARTIN J., Foreign Wire Relations Engineer, Indiana Bell Telephone Co., Indianapolis, Ind.

MacRAE, FRED G., Sales Engineer, Electric Service Supplies Co., Chicago, Ill.

MERLIN, HOWARD R., Electrical Research Engineer, Interborough Rapid Transit Co., New York, N. Y.

NORMAN, HORACE M., Design Engineer, Westinghouse E. & M. Co., East Pittsburgh, Pa.

PERLEY, FRANK G., Industrial Power Engineer, Connecticut Power & Light Co., Norwalk, Conn.

PFEIFFER, CONRAD L., Engineer, Western Electric Co., Chicago, Ill.

QUIRK, WILLIAM G., Supervising Chief Inspector, City of New York, Municipal Bldg., New York, N. Y.

ROSEVEAR, MORRIS B., Engineer, American Brown Boveri Electric Corp., Camden, N. J.

ROSS, LINDSLEY W., Secretary of Employment and Training, Pacific Telephone & Telegraph Co., Seattle, Wash.

RUPP, WELLINGTON, Chief Engineer, Dept. of Public Works of Washington, Olympia, Wash.

RUSSELL, EDWARD G., Electrical Engineer, Dept. of Water & Power, Los Angeles, Calif.

SAALBERG, WILLIAM H., Underground Engineer, The Ohio Power Co., Canton, Ohio.

STAMM, OTTO E., Chief of Planning Bureau, Distribution Dept., N. Y. Edison Co., New York, N. Y.

STANSFIELD, ARTHUR, Electrical Engineer, Manchester Corporation Electricity Department, Manchester, England.

STEELE, GEORGE F., Consulting Engineer, General Electric Co., Boston, Mass.

STEPHENS, HOWARD O., Engineer, Transformer Dept., General Electric Co., Pittsfield, Mass.

SWENSON, GEORGE W., Assistant Professor, University of Minnesota, Minneapolis, Minn.

SWOBODA, H. O., Consulting Engineer, 3400 Forbes St., Pittsburgh, Pa.

THOMAS, JOSEPH E., Supt. of Operation, West Penn Power Co., Pittsburgh, Pa.

VOGDES, FRANCIS B., Research Laboratory, General Electric Co., Schenectady, N. Y.

WAGNER, CHARLES F., Transmission Engineer, Westinghouse E. & M. Co., East Pittsburgh, Pa.

WICKERSHEIM, LYLE W.. Engineer, Southern Calif. Telephone Co., Los Angeles, Calif.

WRIGHT, EARL L., Transformer Specialist, General Electric Co., Philadelphia, Pa.

**RECOMMENDED FOR TRANSFER**

The Board of Examiners, at its meeting held October 5, 1927, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

**To Grade of Fellow**

JOHNSON, J. ALLEN, Electrical Engineer, Niagara Falls Power Co., Niagara Falls, N. Y.

PAULSEN, ALFRED G., General Manager, Venezuela Electric Light Co., Ltd.,Venezuela, S. A.

SLEPIAN, JOSEPH, Research Consulting Engineer, Westinghouse E. & M. Co., East Pittsburgh, Pa.

WAGNER, EDWARD A., Acting Manager, General Electric Co., Pittsfield, Mass.

**To Grade of Member**

ASH, PHILIP P., Chief Signal Draftsman, Louisville & Nashville R. R. Co., Louisville, Ky.

BARMACK, BORIS J., Asst. Engr. of Specifications, Commonwealth Edison Co., Chicago, Ill.

BEEKMAN, ROYCE A., Engineer, General Electric Co., Schenectady, N. Y.

BURNHAM. JOSEPH L., Designing Engineer, General Electric Co., Schenectady, N. Y.

ENOS, HOWARD A., Distribution Engineer, American Gas & Electric Co., New York, N. Y.

EVANS, THOMAS McK., Section Head, General Electric Co., Fort Wayne, Ind.

FITTING, RALPH U., Valuation Engineer, Los Angeles Gas & Elec. Corp., Los Angeles, Calif.

FOSTER, JOSEPH T., Purchasing Assistant to Vice President, Public Service Corp. of N. J., Newark, N. J.

MANSFIELD, PERCY B., Electrical Engineer, (Sales) Armor Electric Mfg. Co., Jamestown, N. Y.

MARYATT, ELMER F., Assistant Engineer, Pacific Gas & Elec. Co., San Francisco, Calif.

McDONALD, JAMES W., Designing Engineer, Duquesne Light Co., Pittsburgh, Pa.

McMANUS, JOHN A., Confidential Assistant to Dr. Elihu Thomson, and Patent Attorney, General Electric Co., West Lynn, Mass.

MESSNER, ROY L., Division Transmission Engineer, Pacific Tel. & Tel. Co., Sacramento, Calif.

MURRAY, W. A., Assistant Professor of Elec. Engg., Montana State College, Bozeman, Mont.
REID, ROBERT, Electrical Valuation Engineer, Great Western Power Co., San Francisco, Calif.
SANDS, HOWARD T., Executive, Electric Bond & Share Co., New York, N. Y.
SCHILLER, AVERY R., Vice President in charge of Operations, Public Service Co. of N. H., Manchester, N. H.
SISMEY, ERIC D., Station Chief, Powerhouse No. 1, Southern Calif. Edison Co., Big Creek, Calif.
SMITH, MORRIS B., Panel Sales Engineer, Crouse Hinds Co., Syracuse, N. Y.
STEIN, I. MELVILLE, Asst. Sales Manager, Leeds & Northrup Co., Philadelphia, Pa.
WELCH, ALFRED F., Engineer, Fractional H. P. Division, General Electric Co., Fort Wayne, Ind.
WILTSE, STANLEY B., Assistant Professor of Elec. Engg., Rensselaer Polytechnic Institute, Troy, N. Y.
WRIGHT, RALPH H., General Engineer, Westinghouse E. & M. Co., East Pittsburgh, Pa.

## APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before November 30, 1927.

Andriessen, R., Canadian Crocker Wheeler, Ltd., St. Catharines, Ont., Can.
Ball, T. F., (Member), University of Carolina, Columbia, S. C.
Baruch, M., 1425 Grand Concourse, New York, N. Y.
Batkay, F., New York Telephone Co., New York, N. Y.
Beindorf, L. J., Western Electric Co., Inc., Chicago, Ill.
Bennett, J. S., New York Central Electric Corp., Hornell, N. Y.
Bordeau, S. P., Electric Machinery Mfg. Co., Minneapolis, Minn.
Brodie, J. E., International General Electric Co., Schenectady, N. Y.
Cangemi, J. F., 15 Schaeffer St., Brooklyn, N. Y.
Chandler, F. H., (Member), Hydro-Electric Power Comm. of Ontario, Toronto, Ont., Can.
Craig, C. F., (Member), American Tel. & Tel. Co., New York, N. Y.
Derrig, J. W., Public Service Gas & Electric Co., Irvington, N. J.
Dorkey, F. C., Rochester Gas & Electric Corp., Rochester, N. Y.
Eadie, T. W., Bell Telephone Co. of Canada, Toronto, Ont., Can.
Ellerby, E., Canadian Westinghouse Co., Ltd., Toronto, Ont., Can.
Erdos, K. F., Illinois Power & Light Corp., St. Louis, Mo.
Enright, J. D., National Electric Light Ass'n., New York, N. Y.
Evans, D. T., Granby Cons. Mining, Smelting & Power Co., Anyox, B. C., Can.
Ewing, R. H., E. A. Lundy Co., Portland, Ore.
Fairlamb, W. F., (Member), Virginia Electric & Power Co., Suffolk, Va.
Farr, J. E., Sargent & Lundy, Chicago, Ill.
Frankenberry, T. H., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
(Applicant for re-election.)
Gardiner, C. E. Jr., Adirondack Power & Light Corp., Schenectady, N. Y.
Gerell, G. W., Union Electric Light & Power Co., St. Louis, Mo.
Gordon, K. H., Pennsylvania Railroad, Altoona, Pa.
Graham, D., Mass. Inst. of Technology, Cambridge, Mass.
Greenwald, J. M., 222 W. 84th St., New York, N. Y.
Greenawalt, J. F., Mountain States Tel. & Tel. Co., Denver, Colo.
Guenther, W. F., Hamilton Hydro-Electric System, Hamilton, Ont., Can.
Hanford, D. R., Electrical Installation, Hastings-on-Hudson, N. Y.
Harris, E. H., General Electric Co., River Works, West Lynn, Mass.
Harrison, W., Maryville, Tenn.
Harvey, G. M., Bell Telephone Co. of Pa., Pittsburgh, Pa.
Hinckley, A. D., Santa Clara Univ., College of Engg., Santa Clara, Calif.
Hirohashi, T., International General Electric Co., Schenectady, N. Y.
Holloway, G. C., Electric Bond & Share Co., New York, N. Y.
Hughes, E. R., (Member), Consulting Engineer, 55 John St., New York, N. Y.
Jones, L. E., Philadelphia Electric Co., Philadelphia, Pa.
Kearney, W. A., American Fork & Hoe Co., Philadelphia, Pa.
Kenworthy, O. D., Lehigh Valley Coal Co., Wilkes-Barre, Pa.
Kimbark, E. W., University of California, Berkeley, Calif.
Kramer, L., 49 W. 87th St., New York, N. Y.
Krouse, A. W., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Lane, A. H., American Tel. & Tel. Co., Boston, Mass.
Lane, R. A., Philadelphia Electric Co., Philadelphia, Pa.
Lawn, G. W., Cons. Mining, Smelting & Power Co., Anyox, B. C., Can.
Leahy, J. F., Northwest Steel Rolling Mills, Seattle, Wash.
Lees, H. S., Wheaton Electric Light Co., Wheaton, Minn.
Maselter, J. E., General Electric Co. Service Shop, St. Louis, Mo.
McCarty, O. P., General Electric Co., Lynn, Mass.
McCracken, H. J., Jr., Dept. of Water & Power, City of Los Angeles, Los Angeles, Calif.
Miller, F. D., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Miller, L. H., (Member), Radio Corp. of America, New York, N. Y.
Moreland, E. S., 807 N. Eldorado St., Stockton, Calif.
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Norton, G. H., So. California Edison Co., Big Creek, Calif.
Nowland, R. L., Bell Telephone Co. of Pa., Pittsburgh, Pa.
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Piazza, F. D., Monongahela West Penn Public Service Co., Fairmount, West Va.
Poniatoff, A. M., General Electric Co., Schenectady, N. Y.
Potter, M. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
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Sackman, G. R., Stuyvesant High School, New York, N. Y.
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Wilcock, W., English Electric Co. of Canada, Ltd., St. Catharines, Ont., Can.
Williams, S. A., with Lee P. Hynes, New York, N. Y.
Willner, H. C., Twin City Rapid Transit Co., Minneapolis, Minn.
Williamson, G., Jr., General Electric Co. Service Shop, Buffalo, N. Y.
Woodman, G. R., So. California Edison Co., Big Creek, Calif.
Total 95

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Eyeberg, H., Commonwealth Works & Railways, Jolimont, Victoria, Aust.
Reehaul, J. S., (Member), Punjab Portland Cement Works, Ltd., N. W. R. Dist. Attock, Punjab, India
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Smith, A. W., Leao & Co., Jaragua, Alagoas, Brazil, S. A.
Srivastava, C. P., Automatic Telephone Exchange, Bharatpur, India
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Burgess, Howard B., Northeastern University

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Cain, George W., Jr., Oregon Agricultural College
Cheney, Reg M., Oregon Agricultural College
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Crumley, Everett T., Montana State College
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Hartford, Orville E., Northeastern University
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Lundstrom, Alexis A., Oregon Agricultural College
Mahan, Kenneth, Oregon Agricultural College
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| **Worcester** | Guy F. Woodward | F. B. Crosby, Morgan Construction Co., 15 Belmont St., Worcester, Mass. |

Total 52

## LIST OF BRANCHES

| Name and Location | Chairman | Secretary | Counselor (Member of Faculty) |
|---|---|---|---|
| **Akron, Municipal University of,** Akron, Ohio | C. R. Delagrange | P. W Bierman | J. T. Walther |
| **Alabama Polytechnic Institute,** Auburn, Ala | T. S. Lynch | P. E. Sandlin | W. W. Hill |
| **Alabama, University of,** University, Ala | Sewell St. John | J. M. Cardwell, Jr. | |
| **Arizona, University of,** Tucson, Ariz | Gary Mitchell | Audley Sharpe | J. C. Clark |
| **Arkansas, University of,** Fayetteville, Ark | Carroll Walsh | W. H. Mann, Jr. | W. B. Stelzner |
| **Armour Institute of Technology,** 3300 Federal St., Chicago, Ill | L. J. Anderson | H. T. Dahlgren | D. P. Moreton |
| **Brooklyn Polytechnic Institute,** 99 Livingston St., Brooklyn, N. Y | James Brown | F. W. Campbell | Robin Beach |
| **Bucknell University,** Lewisburg, Pa | G. B. Timm | A. C. Urffer | W. K Rhodes |
| **California Institute of Technology,** Pasadena, Calif | J. W. Thatcher | J. G. Kuhn | R. W. Sorensen |
| **California, University of,** Berkeley, Calif | A. G. Montin | R. T. Montin | T. C. McFarland |
| **Carnegie Institute of Technology,** Pittsburgh, Pa | N. D. Cole | J. R. Britton | B. C. Dennison |
| **Case School of Applied Science,** Cleveland, Ohio | G. J. Currie | R. C. Taylor | H. B. Dates |
| **Catholic University of America,** Washington, D. C | Wm. S. Sparks | C. S. Daily, Jr. | T. J. MacKavanaugh |
| **Cincinnati, University of,** Cincinnati, O | C. W. Taylor | W. C. Osterbrock | W. C. Osterbrock |
| **Clarkson College of Technology,** Potsdam, N. Y | G. L. Rogers | J. S. Loomis | A. R. Powers |
| **Clemson Agricultural College,** Clemson College, S. C | L. R. Miller | J. U. Wilson | S. R. Rhodes |
| **Colorado, University of,** Boulder, Colo | J. A. Setter | H. R. Arnold | W. C. DuVall |
| **Colorado State Agricultural College,** Fort Collins, Colo | Harold Groat | Howard Steinmetz | H. G. Jordan |
| **Cooper Union,** New York, N. Y | E. T. Reynolds | Wilfred Henschel | N. L. Towle |
| **Denver, University of,** Denver, Colo | G. K. Baker | L. L. Booth | R. E. Nyswander |
| **Drexel Institute,** Philadelphia, Pa | J. E. Young | C. J. Backman | E. O. Lange |
| **Duke University,** Durham, N. C | O. T. Colclough | F. A. Bevacqua | W. J. Seeley |
| **Florida, University of,** Gainesville, Fla | W. H. Johnson | A. C. Dean | J. M. Weil |
| **Georgia School of Technology,** Atlanta, Ga | W. M. McGraw | F. L. Kaestle | E. S. Hannaford |
| **Idaho, University of,** Moscow, Idaho | R. G. Elliott | F. B. Peterson | J. H. Johnson |
| **Iowa State College,** Ames, Iowa | W. H. Curvin | W. H. Stark | F. A. Fish |
| **Iowa, State University of,** Iowa City, Iowa | F. L. Kline | M. B. Hurd | A. H. Ford |
| **Kansas State College,** Manhattan, Kansas | A. M. Young | John Yost | R. G. Kloeffler |

## LIST OF BRANCHES—*Continued.*

| Name and Location | Chairman | Secretary | Counselor (Member of Faculty) |
|---|---|---|---|
| **Kansas, University of,** Lawrence, Kans | Claire Williamson | D. M. Black | G. C. Shaad |
| **Kentucky, University of,** Lexington, Ky | H. M. Otto | D. M. James | W. E. Freeman |
| **Lafayette College,** Easton, Pa | John W. Dagon | H. W. Lovett | Morland King |
| **Lehigh University,** Bethlehem, Pa | H. C. Towle, Jr. | W. D. Goodale, Jr. | J. L. Beaver |
| **Lewis Institute,** Chicago, Ill | L. F. Masonick | G. M. Berg | F. A. Rogers |
| **Louisiana State University,** Baton Rouge, La | R. C. Alley | W. S. Marks | M. B. Voorhies |
| **Maine, University of,** Orona, Maine | R. F. Scott | E. W. Jones | Wm. E. Barrows, Jr. |
| **Marquette University,** 1200 Sycamore St., Milwaukee, Wis | J. R. Adriansen | H. J. Lavigne | J. F. H. Douglas |
| **Massachusetts Institute of Technology,** Cambridge, Mass | W. M. Hall | H. F. Krantz | W. H. Timbie |
| **Michigan State College,** East Lansing, Mich | K. E. Hunt | S. W. Luther | L. S. Foltz |
| **Michigan, University of,** Ann Arbor, Mich | L. J. VanTuyl | W. E. Reichle | B. F. Bailey |
| **Milwaukee, Engineering School of,** 415 Marshall St., Milwaukee, Wis | Joseph Havlick | H. F. Brundage | John D. Ball |
| **Minnesota, University of,** Minneapolis, Minn | G. C. Brown | G. C. Hawkins | H. Kuhlmann |
| **Mississippi Agricultural & Mechanical College,** A. & M. College, Miss | H. M. Stainton | R. S. Kersh | L. L. Patterson |
| **Missouri School of Mines & Metallurgy,** Rolla, Mo | H. H. Brittingham | E. J. Gregory | I. H. Lovett |
| **Missouri, University of,** Columbia, Mo | C. E. Schooley | W. D. Johnson | M. P. Weinbach |
| **Montana State College,** Bozeman, Mont | W. F. Kobbe | G. E. West | J. A. Thaler |
| **Nebraska, University of,** Lincoln, Neb | W. A. Van Wie | Keith Davis | F. W. Norris |
| **Nevada, University of,** Reno, Nevada | K. K. Knopf | Clark Amens | S. G. Pálmer |
| **Newark College of Engineering,** 367 High St., Newark, New Jersey | E. S. Bush | Henry L. Harrison | J. C. Peet |
| **New Hampshire, University of,** Durham N. H | S. S. Appleton | H. B. Rose | L. W. Hitchcock |
| **New York, College of the City of,** 139th St. & Convent Ave., New York, N. Y | Joseph Leipziger | A. H. Rapport | Harry Baum |
| **New York University,** University Heights, New York, N. Y | J. F. Torpie | R. J. Fluskey | J. Loring Arnold |
| **North Carolina State College,** Raleigh, N. C | J. C. Davis | T. C. Farmer | C. W. Ricker |
| **North Carolina, University of,** Chapel Hill, N. C | D M. Holshouser | W. C. Burnett | P. H. Daggett |
| **North Dakota, University of,** University Station, Grand Forks, N. D | Alfred Botten | Nels Anderson | D. R. Jenkins |
| **Northeastern University,** 316 Huntington Ave., Boston 17, Mass | L. A. Smith | C. S. Porter | Wm. L. Smith |
| **Notre Dame, University of,** Notre Dame, Ind | Charles Topping | George Conner | J. A. Caparo |
| **Ohio Northern University,** Ada, O | John Simmons | Verl Jenkins | I. S Campbell |
| **Ohio State University,** Columbus, O | A. B. Crawford | L. G. Stewart | F. C. Caldwell |
| **Ohio University,** Athens, O | Clarence Kelch | H. W. Giesecke | A A. Atkinson |
| **Oklahoma A. & M. College,** Stillwater, Okla | Benny Fonts | Jerry Robertson | Edwin Kurtz |
| **Oklahoma, Uiversity of,** Norman, Okla | Dick Mason | S. Hannon | F. G. Tappan |
| **Oregon State College,** Corvallis, Ore | J D. Hertz | Richard Setterstrom | F. O. McMillan |
| **Pennsylvania State College,** State College, Pa | Carl Dannerth | W. J. Gorman | L. A. Doggett |
| **Pennsylvania, University of,** Philadelphia, Pa | Wm. H. Hamilton | S. R. Warren, Jr. | C. D. Fawcett |
| **Pittsburgh, University of,** Pittsburgh, Pa | M. G. Jarrett | D. P. Mitchell | H. E. Dyche |
| **Princeton University,** Princeton, N. J | R. W. MacGregor, Jr. | W. Wilson | Malcolm MacLaren |
| **Purdue University,** Lafayette, Indiana | H. L. Lindstrom | H. A. Hartley | A. N. Topping |
| **Rensselaer Polytechnic Institute,** Troy, N. Y | W. F. Hess | S. B. Morehouse | F. M. Sebast |
| **Rhode Island State College,** Kingston, R. I | C. F. Easterbrooks | Charles Miller | Wm. Anderson |
| **Rose Polytechnic Institute,** Terre Haute, Ind | Arthur Drompp | J. F. Payne | C. G. Knipmeyer |
| **Rutgers University,** New Brunswick, N. J | N. A. Kieb | J. E. Conover | |
| **Santa Clara, University of,** Santa Clara, Calif | R. P. O'Brien | C. E. Newton | |
| **South Dakota State School of Mines,** Rapid City, S. D | D. A. White | Robert Mytinger, Jr. | J. O. Kammerman |
| **South Dakota, University of,** Vermillion, S. D | Stanley Boegler | L. E. Crowell | B. B. Brackett |
| **Southern California, University of,** Los Angeles, Calif | Lester Bateman | L. F. Slezak | P. S. Biegler |
| **Stanford University,** Stanford University, Calif | D. E. Chambers | T. L. Lenzen | T. H. Morgan |
| **Stevens Institute of Technology,** Hoboken, N. J | D. B. Wesstrom | G. E. Witham | F. C. Stockwell |
| **Swarthmore College,** Swarthmore, Pa | T. C. Lightfoot | W. F. Denkhaus | Lewis Fussell |
| **Syracuse University,** Syracuse, N. Y | E. D. Lynde | R. C. Miles | C. W. Henderson |
| **Tennessee, University of,** Knoxville, Tenn | F. N. Green | B. M. Gallaher | C. A. Perkins |
| **Texas, A. & M. College of,** College Station, Texas | J. L. Pratt | H. W. Whitney | C. C. Yates |
| **Texas, University of,** Austin, Texas | G. E. Schade | L. R. Bagwell | J. A. Correll |
| **Utah, University of,** Salt Lake City, Utah | C. E. White | Junior Petterson | J. F. Merrill |
| **Virginia Military Institute,** Lexington, Va | W. F. R. Griffith | F. Barkus | S. W. Anderson |
| **Virginia Polytechnic Institute,** Blacksburg, Va | R. M. Hutcheson | | Claudius Lee |
| **Virginia, University of,** University, Va | H. D. Forsyth | C. H. Davis, Jr. | W. S. Rodman |
| **Washington, State College of,** Pullman, Wash | Harry Wall | E. G. Peters | R. D. Sloan |
| **Washington University,** St. Louis, Mo | R. L. Belshe | J. G. Mazanec, Jr. | H. G. Hake |
| **Washington, University of,** Seattle, Wash | Wm. Bolster | Arthur Peterson | G. L. Hoard |
| **Washington and Lee University,** Lexington, Va | R. E. Kepler | Bernard Yoepp | R. W. Dickey |
| **West Virginia University,** Morgantown, W. Va | G. B. Pyles | C. C. Coulter | A. H. Forman |
| **Wisconsin, University of,** Madison, Wis | John Sargent | Leonard Saari | C. M. Jansky |
| **Worcester Polytechnic Institute,** Worcester, Mass | D. A. Calder | C. H. Kauke | H. A. Maxfield |
| **Wyoming, University of,** Laramie, Wyoming | J. O. Yates | E. C. Moudy | G. H. Sechrist |
| **Yale University,** New Haven, Conn | W. J. Brown | W. T. Kelly, Jr. | C. F. Scott |

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# DIGEST OF CURRENT INDUSTRIAL NEWS

## NEW CATALOGUES AND OTHER PUBLICATIONS

*Mailed to interested readers by issuing companies*

**Motors.**—Bulletin 153, 6 pp. Describes the new Wagner split-phase, fractional horsepower, induction motor Wagner Electric Corporation, St Louis, Mo.

**Electric Heating Equipment.**—Bulletin describes complete electric portable and stationary heaters, and electric strip heaters. The Martindale Electric Company, 1254 West 4th Street, Cleveland, Ohio.

**Circuit Breakers**—Bulletin 11, 28 pp. Describes Pacific Electric high voltage switches and oil circuit breakers. The bulletin is illustrated with diagrams and typical installations. Pacific Electric Manufacturing Company, 5815 Third Street, San Francisco, Cal.

**Scale Drawings For Substation Layouts.**—A seven-page folio for electrical draftsmen giving scale drawings of high tension engineering equipment. These seven engineering sheets give scales of 1/8″, 3/16″, 1/4″, 3/8″, 1/2″, 3/4″ and 1″ to one foot and will be found useful in making up substation layouts. Delta-Star Electric Company, 2400 Block Fulton Street, Chicago, Ill.

**Power Demand Limitator.**—Bulletin 11. Describes the "Edmoore" power demand limitator, an electrical device for automatically controlling and limiting power demands or peak loads on electric power systems for consumers. It is claimed that by its use considerable savings are effected. The device is generally connected to the main incoming power lines of a consumer's plant so as to summate all power. Edward T. Moore, 500 Cahill Building, Syracuse, N. Y.

**Electrical Laboratory Apparatus.**—Bulletin GEA 450A, 60 pp. Describes General Electric electrical laboratory apparatus and educational service. The bulletin illustrates a wide variety of equipment, including motors and generators, synchronous converters, steam turbines, controllers and circuit breakers, transformers, high voltage testing equipment, voltage regulators, measuring instruments, oscillographs, etc. The student engineering courses and illustrated lecture service, motion picture films and data service are also briefly outlined. General Electric Company, Schenectady, N. Y.

## NOTES OF THE INDUSTRY

**Corning Glass Works, Corning, N. Y.,** has appointed W. W. Kirk as California representative, with headquarters at 211 I. W. Hellman Building, Los Angeles, to handle only the sales of PYREX power insulators.

**The Martindale Electric Company, 1254 West 4th Street, Cleveland, Ohio,** manufacturers, agents and importers of motor maintenance equipment products, has recently opened a branch in New York City at 6 East 46th Street, in charge of E. H. Mitcham.

**The Roller-Smith Company, 233 Broadway, New York,** announces the appointment of the D. H. Braymer Equipment Company, W. O. W. Building, Omaha, Nebraska, as its representative for Nebraska and western Iowa. Mr. D. H. Braymer is at the head of this organization. The D. H. Braymer Equipment Company will handle Roller-Smith instruments, relays and circuit breakers in the territory specified.

**The Lincoln Electric Company, Cleveland,** manufacturers of "Linc-Weld" motors and "Stable-Arc" welders, has appointed E. A. Thornwell, of Atlanta, as representative for Georgia and eastern Tennessee. Mr. Thornwell has been actively associated with the electric industry in Atlanta and Pittsburgh since his graduation in 1904 from Clemson College. John Van Horn, factory engineer for the Lincoln Electric Company, has been attached to the Atlanta office to assist Mr. Thornwell.

**The Maring Wire Company, Muskegon, Michigan,** manufacturers of magnet wire, announces the appointment of Thomas F. Kelly as sales manager. Since graduating from the University of Wisconsin in electrical engineering, Mr. Kelly has been intimately associated with the electrical industry. His activity in the magnet wire business covers fifteen years, seven of which were spent in the sales department of the American Electrical Works of Phillipsdale, R. I., and for the past eight years, up until January 1, 1927, Mr. Kelly was sales manager for the American Enameled Magnet Wire Company, Muskegon, Michigan.

**The Timken Roller Bearing Company, Canton, Ohio,** and M. B. U. Dewar, of London, England, have together purchased from Vickers, Ltd., all of the capital stock of British Timken, Ltd. This purchase gives Timken complete control throughout the world of the manufacture and sale of Timken bearings. Formerly the British Timken, Ltd., operated for many years under license from the Timken Roller Bearing Company.

**The Hazard Manufacturing Company, Wilkes-Barre, Penn.,** has separated its two distinct lines of business into two companies, retaining its present corporate name in the manufacture and sale of insulated wires and cables. A corporation chartered in Pennsylvania as the Hazard Wire Rope Company will take over the manufacture and sale of wire rope formerly carried on by the Hazard Manufacturing Company. The present management of the parent company is retained by both organizations.

**Large Westinghouse Generator Units for Steel and Paper Mills.**—The Youngstown Sheet and Tube Company, Youngstown, Ohio, has placed an order with the Westinghouse Electric & Manufacturing Company for an 18,000 kw. turbine generator unit.

The Anglo-Canadian Pulp and Paper Mills of Quebec, Canada, through the Canadian Westinghouse Company, Hamilton, Canada, has ordered a 7500 kw. turbine generating unit. Both units will be built at the South Philadelphia Works.

**Wire Companies Consolidate.**—A merger of five large electrical wire and cable manufacturing companies is under way, to be known as the General Cable Corporation, which will have net assets of $50,000,000. The projected merger will own and operate the businesses of the Dublo Manufacturing Corporation, the Rome Wire Company, the Safety Cable Company and the Standard Underground Cable Company, and the sheet, rod and wire mills of the Baltimore Copper Smelting & Rolling Company. A special meeting of the stockholders has been called for November 10, when it is expected that the actions of the respective Boards of Directors will be ratified. Plants of the General Cable Corporation will be located at Bayonne, Perth Amboy, Newark and Harrison, N. J.; Rome and Buffalo, N. Y.; Pawtucket, R. I.; Baltimore, Chicago, Pittsburgh, St. Louis, Fort Wayne, Ind., Oakland, Cal. and Hamilton, Ontario. The general Cable Corporation expects to retain the executives and staffs now managing the various plants.

**Sales and Profits of G-E.**—The General Electric Company sales billed for the first nine months of 1927, announced October 18 by President Gerard Swope, amounted to $225,959,610.89 compared with $229,638,216.24 for the corresponding period last year. Profit available for dividends on common stock for the nine months of 1927 was $33,262,241.20 compared with $30,051,619.77 for the same nine months of 1926.

Orders received for the three months ended September 30, 1927, amounted to $77,420,263, compared with $81,587,917 for the third quarter of 1926, a decrease of five per cent. For the nine months ended September 30, orders totalled $233,076,091, representing a decrease of six per cent compared with $246,993,637 in the corresponding nine months of 1926.